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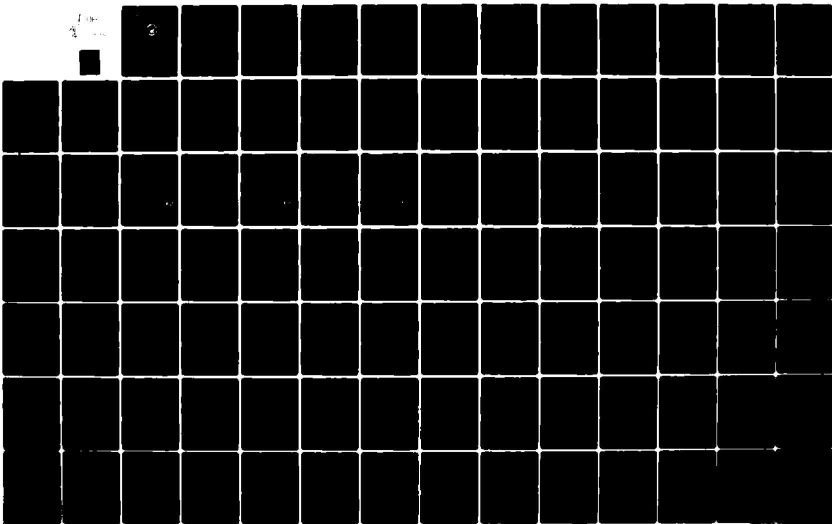

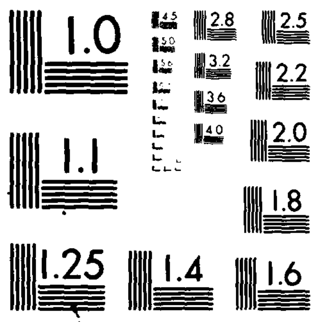

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THESIS

COMPUTER INVESTIGATION OF VHF, UHF
AND SHF FREQUENCIES FOR
MARINE CORPS PACKET RADIO USAGE

by

Thomas George Kane

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Thesis Advisor: J. M. Wozencraft

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A098085	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Computer Investigation of VHF, UHF and SHF Frequencies for Marine Corps Packet Radio Usage		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; December 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas George Kane		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE December 1980
		13. NUMBER OF PAGES 123
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Packet Radios
Frequency Determination
Link Equations
Marine Amphibious Brigade
Network Connectivity
Interception Vulnerability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis is a computer investigation of the VHF, UHF and SHF frequency bands for possible use by Marine Corps Packet Radio systems. It uses the STAR Terrain Model to analyze the different connectivity patterns that appear as the units of the Marine Amphibious Brigade move across the battlefield. The problem of enemy intercept of friendly traffic is also discussed and the units with a high probability of being intercepted are displayed pictorially.

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Computer Investigation of VHF, UHF and SHF Frequencies for Marine Corps Packet Radio Usage

by

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Captain, U.S. Marine Corps
B.S.I.M., Purdue University, 1974

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1980

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ABSTRACT

This thesis is a computer investigation of the VHF, UHF and SHF frequency bands for possible use by Marine Corps Packet Radio systems. It uses the STAR Terrain Model to analyze the different connectivity patterns that appear as the units of the Marine Amphibious Brigade move across the battlefield. The problem of enemy intercept of friendly traffic is also discussed and the units with a high probability of being intercepted are displayed pictorially.

TABLE OF CONTENTS

I. INTRODUCTION

Packet Radio (PR) is a technology that extends the application of packet switching, which evolved for networks of point-to-point communication lines, into the area of broadcast radio. It offers a highly effective way of using a multiple-access radio channel, with potentially large numbers of mobile users, to support digital communications over a wide geographic area.

Users in a packet radio network are assumed to share common radio channels, access to which is controlled by microprocessors in the packet radios. The unit of transmission in a packet radio network is called a packet. It contains a number of data bits and is usually variable in length. A packet includes all addressing and control information necessary to correctly route the packet to its final destination. Each packet wends its way from node to node through the network until it arrives at its final destination and is delivered.

An essential attribute of any network is its ability to provide full connectivity among all network nodes [Ref. 1]. It is this connectivity that will be examined in this report. The nodes in this network will be the units that comprise the Marine Amphibious Brigade (MAB). The units will be spread over a battlefield such that their positions relative to one another will be in keeping with current doctrine. The battlefield will

be the STAR model of the Fulda Gap region in West Germany, which is currently being used by the U.S. Army for combat simulation [Ref. 2].

II. LINK EQUATIONS FOR PACKET RADIOS

A. GENERAL

Ground radio links are subject to severe variations in received signal strength due to local variations in terrain and foliage. In addition, reflections give rise to multiple signal paths which lead to distortion and fading as signals with different delays interfere at a receiver. As a result, RF connectivity is difficult to predict in detail and may change abruptly as units move about the battlefield.

If a packet radio network existed such that all radios were sited with a radio line-of-sight path to nearby neighbors, then the predictability and reliability of such a network would be greatly increased. Particularly if a packet radio network existed such that all radios possessed an optical line-of-sight to nearby neighbors, then analysis of the network would be greatly simplified.[1] The stringent requirement for an optical line-of-sight over the earth will be used in this report to simplify the calculations.

---

[1]An optical line-of-sight exists when a straight line can be drawn between the two antennas, and the line is not intersected by the earth. A radio line-of-sight is an RF path between a transmitter and a receiver. This path can exist in the absence of an optical line-of-sight because of obstacle gain and diffraction.

B. LINK EQUATION

The link equation used in this report is:

$$\frac{P_T\ G_T\ G_R}{k\ T_o\ B_{Rf}\ F_s\ L} \geq SNR_{min}$$

where P_T = transmitter output power (watts)

G_T = transmitting antenna gain

G_R = receiving antenna gain

L = link loss

k = Boltzman's constant (-228.6 dB)

T_o = noise temperature (24.6 dB)

B_{Rf} = RF bandwidth of receiver

F_s = system noise figure

SNR_{min} = signal-to-noise ratio at receiver input corresponding to minimum acceptable message quality

The link loss can consist of the following losses.

$$L = [L_s](L_{O_2} - H_2O)(L_{Rain})(L_T)(L_R)(L_p)(L_F)$$

Here:

. $L_s = (\frac{4\pi d}{\lambda})^2$ is the spreading loss (for free-space),

. $L_{O_2} - H_2O$ is the loss due to oxygen and water vapor absorption at frequencies above about 10 GHz,

- L_{Rain} is the loss due to rainfall attenuation at frequencies above about 3 GHz
- L_T and L_R are the losses associated with the transmitting and receiving stations,
- L_p includes incidental losses, and
- L_F is the loss associated with foliage penetration.

Therefore the link equation is:

$$\frac{P_T\ G_T\ G_R}{k\ T_o\ B_{rf}\ F_s\ [L_s](L_{O_2} - H_2O)(L_{Rain})(L_T)(L_R)(L_p)(L_F)} \geq SNR_{min}$$

For the analysis of the connectivity of the MAB's radio network the following parameters were given.

(1) Both transmit and receive antennas were omnidirectional in the horizontal plane and had a 30° beamwidth in the vertical plane.

(2) The transmit power was 1 watt.

(3) The data rate was 16 kbs with a $P_e \leq 10^{-6}$.

(4) The system noise figure was 15 dB, $(L_T)(L_R)$ was 3 dB, and L_p was 1 dB.

To find the SNR_{min} that will give a $P_e \leq 10^{-6}$ we have

$$P_e \leq \frac{1}{2}\ \text{erfc}\ \sqrt{z}$$

where z is the SNR_{min} [Ref. 3]. This gives a SNR_{min} of 10.53 dB, or about 11 dB for PRK.

To get the gain of the transmit and receive antennas, which are omni-directional in the horizontal plane and have a 30° beamwidth in the vertical plane we have the following equation.

Directive Gain G_T, G_R

$$G_T = G_R = \frac{4\pi r^2}{\text{area}} = \frac{4\pi r^2}{(\theta r)(\phi r)} = \frac{4\pi}{\theta\phi} \quad \text{in radians}$$

or

$$G_T = G_R = \frac{4\pi}{[\frac{2\pi}{360}\ \theta^\circ][\frac{2\pi}{360}\ \phi^\circ]} = \frac{360^2}{\pi\theta^\circ\phi^\circ} = \frac{41253}{\theta^\circ\phi^\circ} \quad \text{in degrees}$$

$$G_T = G_R = \frac{41253}{(30)(360)} = 3.8197 = 5.82 \text{ dB} .$$

Thus for P_T = 1 watt = 0 dBw and B_{RF} = 2 x 16 kbps the link equation becomes

$$\frac{0\text{ dB} + 5.82\text{ dB} + 5.82\text{ dB}}{-228.6\text{dB}+24.6\text{dB}+45\text{dB}+15\text{dB}[L_s](L_{O_2}-H_2O)(L_{Rain})+3\text{dB}+1\text{dB}+(L_F)\text{dB}} \geq 11\text{ dB}$$

or

$$L_{dB} = [L_s(L_{O_2} - H_2O)]_{dB} + [L_{Rain}]_{dB} + [L_F]_{dB} \leq 140.64 \text{ dB}$$

Therefore, the attenuation due to path loss, rain, and foliage must be less than or equal to about 141 dB. It is this link loss of 141 dB that was used in the model to determine whether or not a link "existed." All combinations of transmitters and receivers were analyzed to find links that had losses of less than 141 dB.

C. PATH LOSS

The minimum theoretical path loss on a radio link in free-space is given by the following formula.

$$L_s = \text{Loss}_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2$$

For a ground radio link, the path loss of free-space may be approached on a link having a radio line-of-sight, although even under this desirable condition diffraction and multipath phenomena can greatly reduce received signal power. Average path attenuation exceeds that of a free-space radio link by a significant amount in the ground radio environment, depending on the type of terrain and the elevation of the radio antenna. The curves in Figures 1 and 2 show average path loss as a

function of link range for a frequency of 1.080 GHz, and illustrate these dependencies for two different transmitter heights [Ref. 4]. These curves are typical also of propagation at UHF.

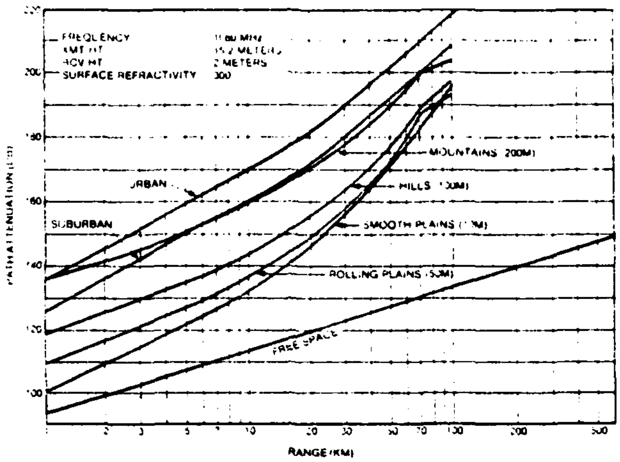
It is worth noting that the variation of mean path loss as a function of frequency is typically much less than the variations due to terrain at a particular frequency [Ref. 1]. The curves shown reflect average values of path loss which apply to a link of given length which is randomly selected without regard to user siting. Well sited radios will typically encounter less path loss than shown in the curves [Ref. 1].

Bullington [Ref. 5] and later Jordan and Balmain [Ref. 6] have developed a simplified propagation formula for transmission in the VHF/UHF range when the elevated transmitting and receiving antennas are far apart. Their approximations are:

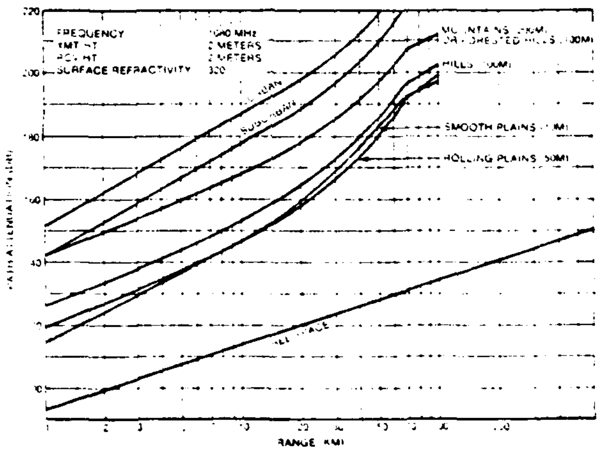
(1) The surface wave can be neglected in comparison with the space wave.

(2) The angle of incidence of the wave with the earth (hence the angle of reflection) is very small so that the reflection factor equals -1.

When the approximations used are valid, the received field strength is proportional to the height of the transmitting antenna, the height of the receiving antenna, and inversely proportional to the square of the distance between them [Refs. 5 and 6].



Path loss versus range. 15-m transmitter height.



Path loss versus range. 2-m transmitter height.

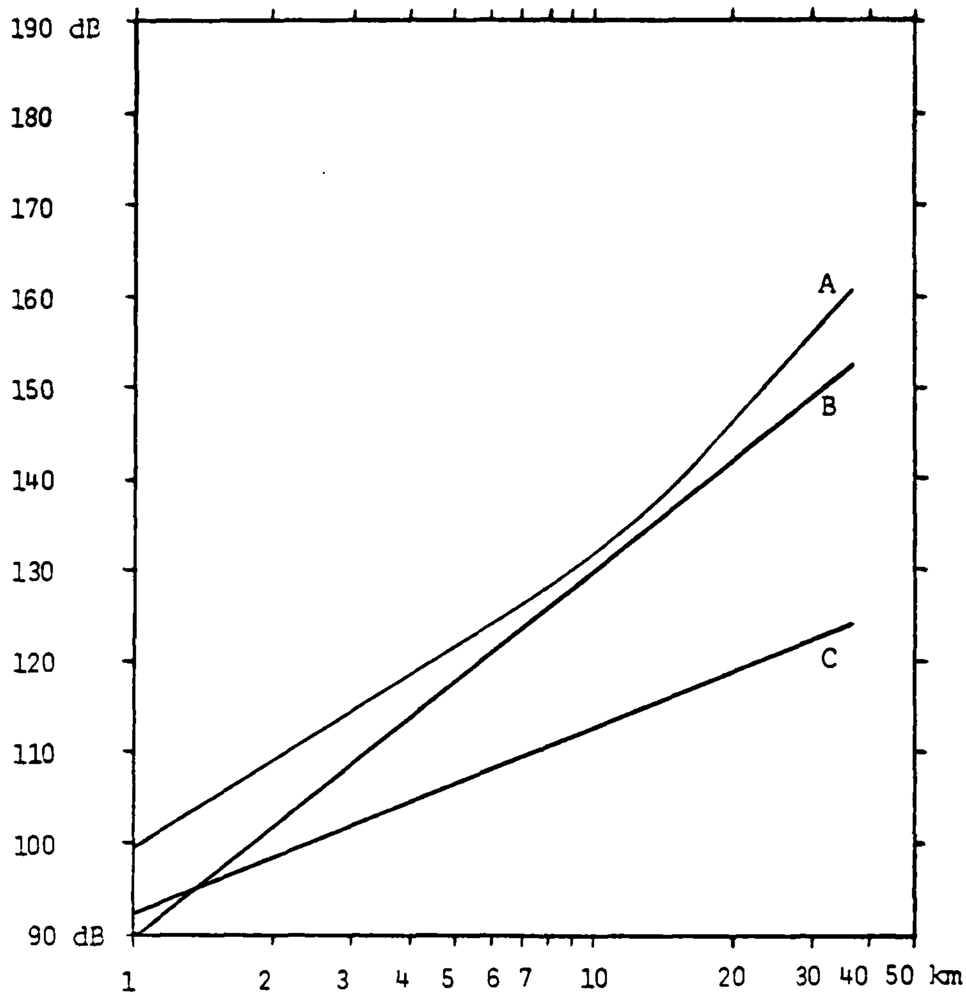
Figures 1 and 2. Path loss versus range [Ref. 4].

$$L_s = \text{Loss} = \left(\frac{d^2}{h_T h_R}\right)^2$$

where h represents the heights of the antennas and d represents the distance between them. This relation is independent of frequency and is valid as long as the loss is more than the free-space loss. Figure 3 shows the free-space loss, the loss encountered over "smooth plains" from Figure 1, and the loss associated with Bullington's equation for a transmit antenna height of 15.2 meters and a receive antenna height of two meters. Figure 4 represents the same data but with a transmit antenna height of two meters. For both graphs, the error is less than 5 dB over the range of interest, which is from a few to about 10 km. Therefore Bullington's equation was used in this thesis to predict path losses in the VHF and UHF regions. The equation is valid as long as it produces losses greater than the free-space loss. Therefore, the model uses the larger of the two losses in calculating link loss.

D. ATTENUATION BY FOLIAGE

Another factor that affects the link loss is the attenuation caused by foliage penetration. Nathanson [Ref. 7] referenced a previously defined equation by Saxton and Lane [Ref. 8] for attenuation in the frequency range from 100 MHz to 3 GHz. He stated that for either antenna polarization, attenuation by trees with leaves in that range is given

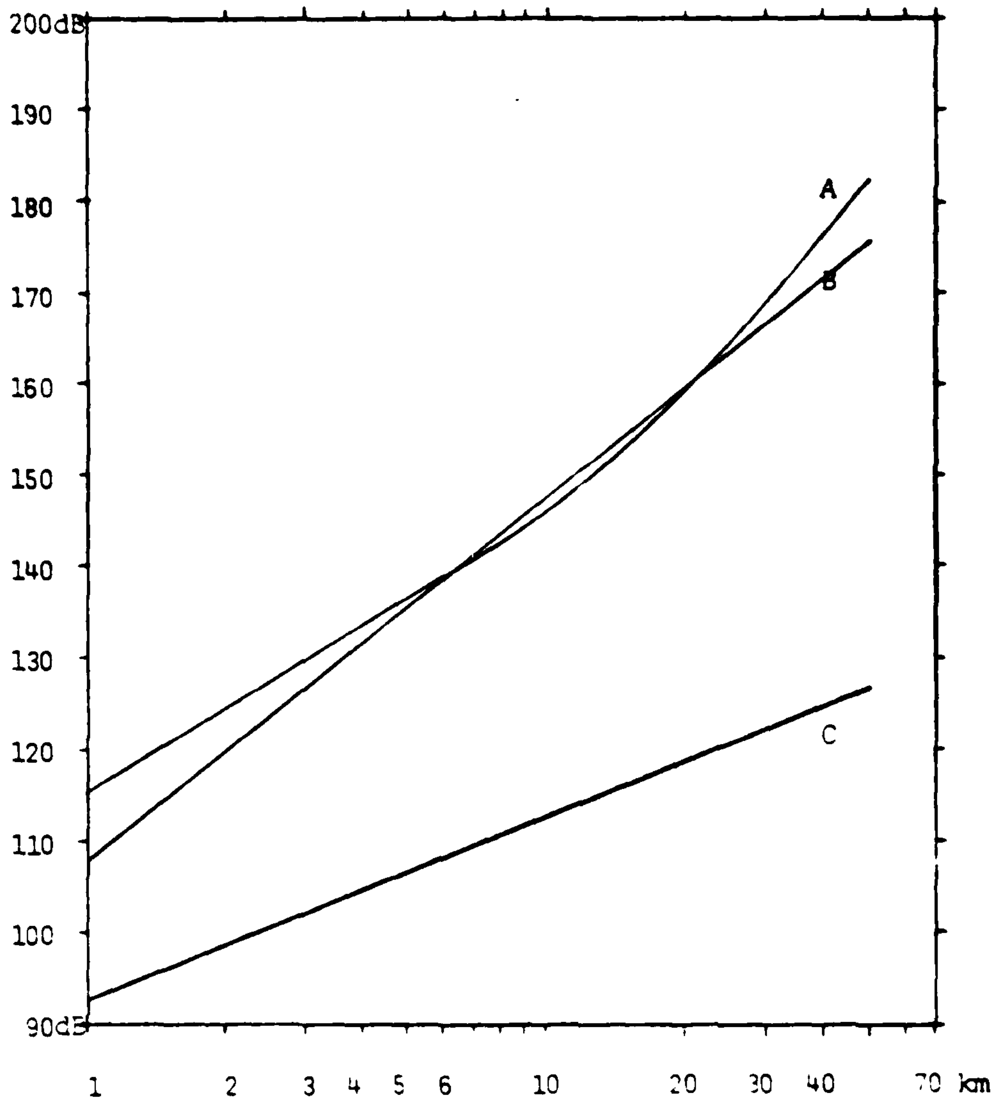


A - Smooth plains

B - Bullington's loss equation

C - Free Space loss

Figure 3. Comparison of Bullington's loss equation vs. free space loss, for a transmitter height of 15.2 meters



A - Smooth plains

B - Bullington's loss equation

C - Free Space loss

Figure 4. Comparison of Bullington's loss equation vs. free space loss, for a transmitter height of 2 meters

approximately by

$$A = 0.25 f^{3/4} \text{ (dB/m)}$$

where f is the carrier frequency in gigahertz and A is attenuation in dB per meter. This equation is used to calculate attenuation from foliage penetration in the model.

E. ATTENUATION OF MILLIMETER WAVES

As shown in Figure 5, at frequencies above about 10 GHz, transmission of millimeter waves through the atmosphere is subject to attenuation caused by resonances of oxygen and water vapor molecules. Attenuation by precipitation, primarily rain, and attenuation associated with penetrating tree foliage also play a key role.

For highly reliable operations at millimeter waves, attenuation by rain is the dominent factor in determining the reliability of the circuit. Figures 6a, b and c were developed by Dudzinsky [Ref. 9] and give required margins for three different levels of reliability. For various frequencies, Figure 6a has as abscissa the path length and gives as an ordinate the margin that will not be exceeded by attenuation due to rain for 99.9% of the time.

The attenuation over a free-space path through a clear atmosphere is simply the sum of the spreading loss $(4\pi d/\lambda)^2$ and the loss due to oxygen and water vapor absorption. The

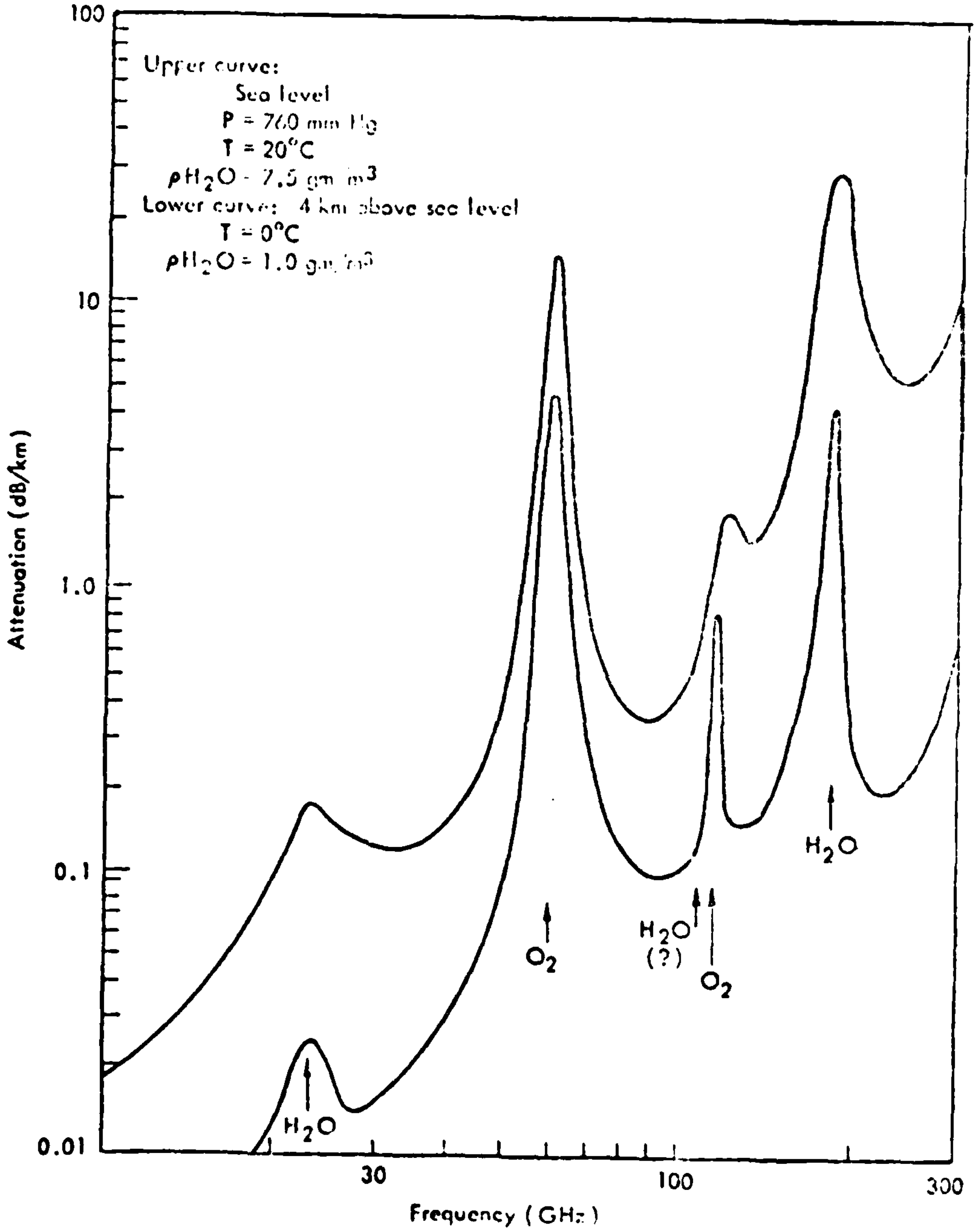


Figure 5. Horizontal attenuation due to oxygen and water vapor [Ref. 9].

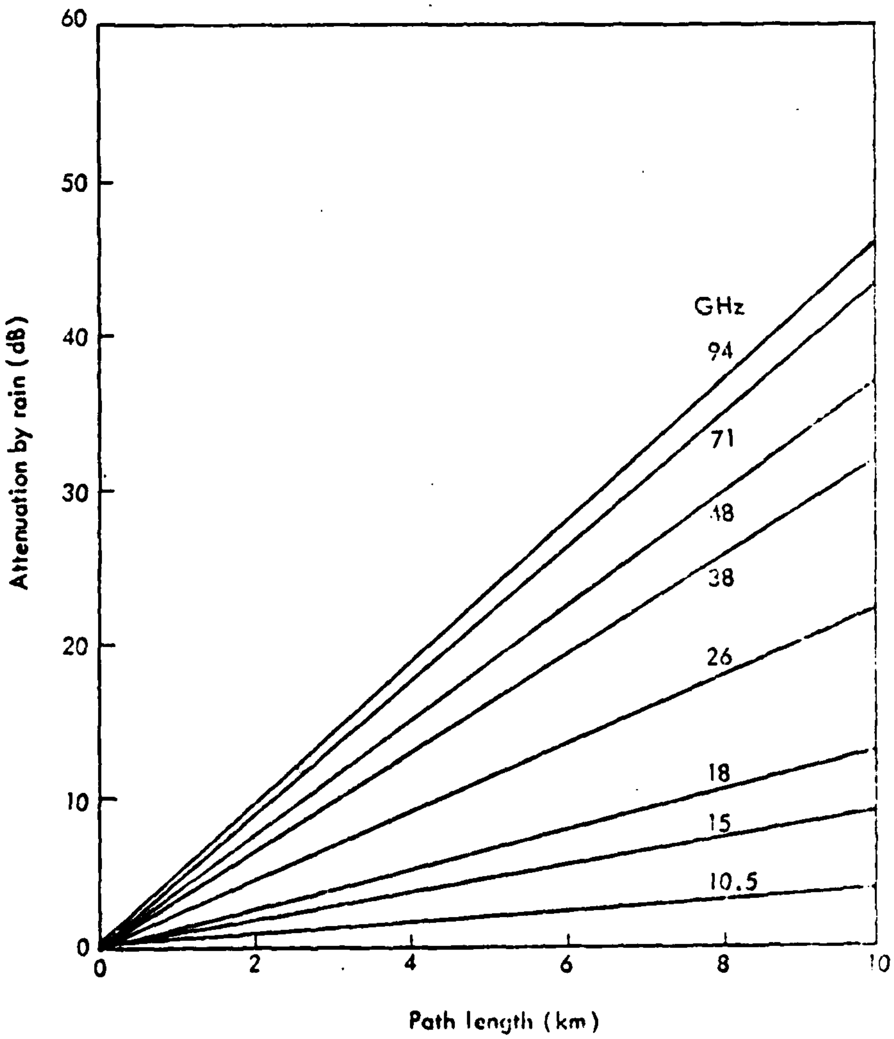


Figure 6a. Attenuation by rain as a function of path length for 99.9% reliability [Ref. 9].

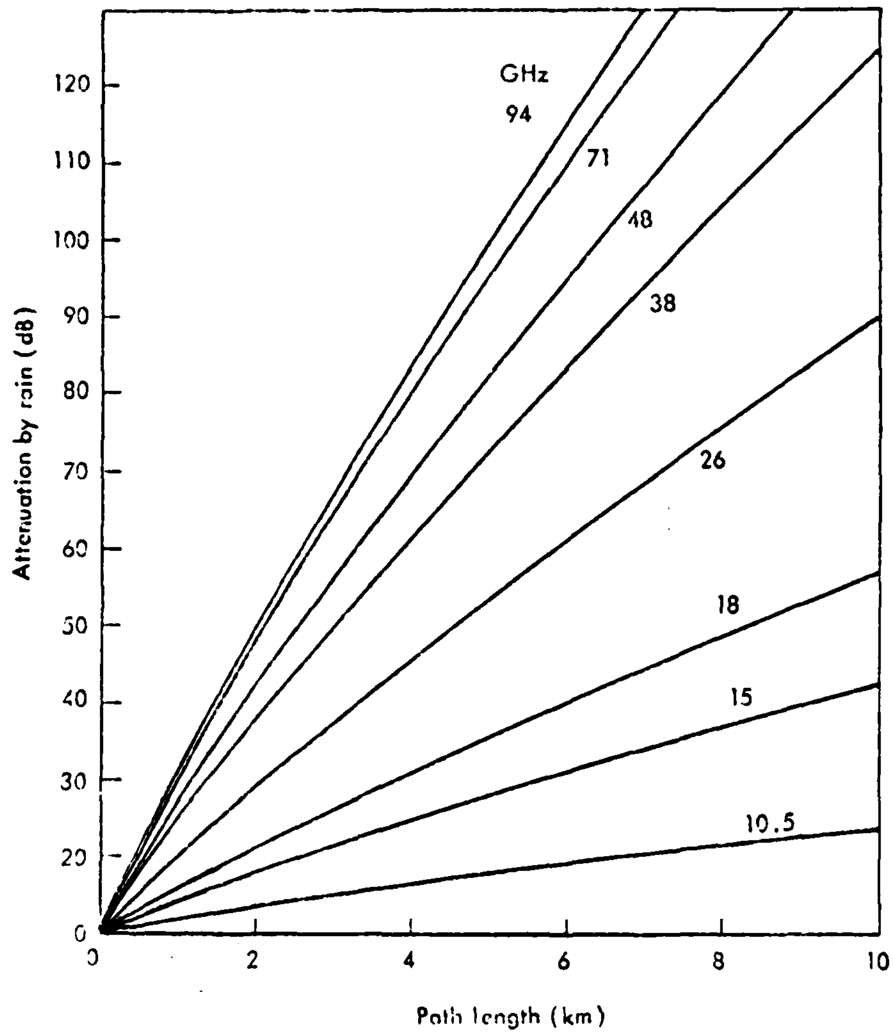


Figure 6b. Attenuation by rain as a function of path length for 99.99% reliability [Ref. 9].

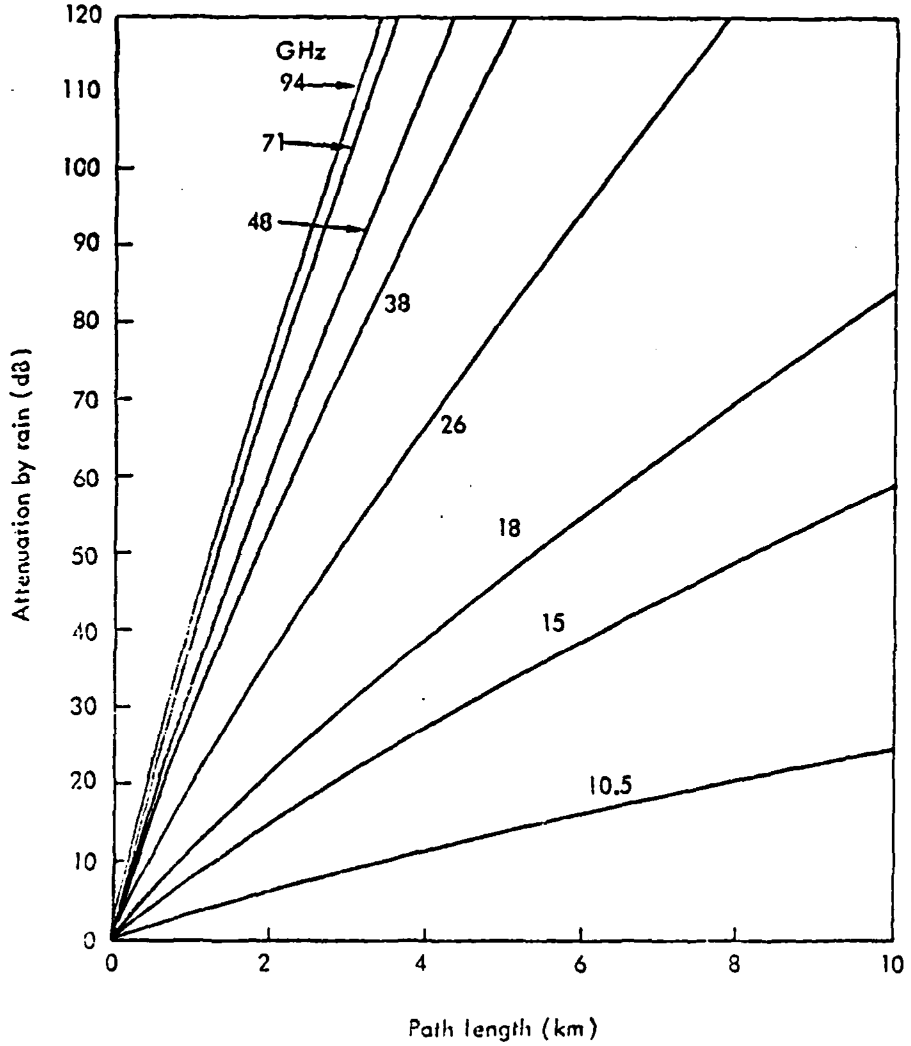


Figure 6c. Attenuation by rain as a function of path length for 99.999% reliability [Ref. 9].

dependence of this attenuation on path length can be represented by curves such as those of Figure 7 [Ref. 9]. These curves can be used together with curves from Figures 6 to estimate the performance of millimeter-wave communications links operating through the atmosphere and in the presence of rainfall.

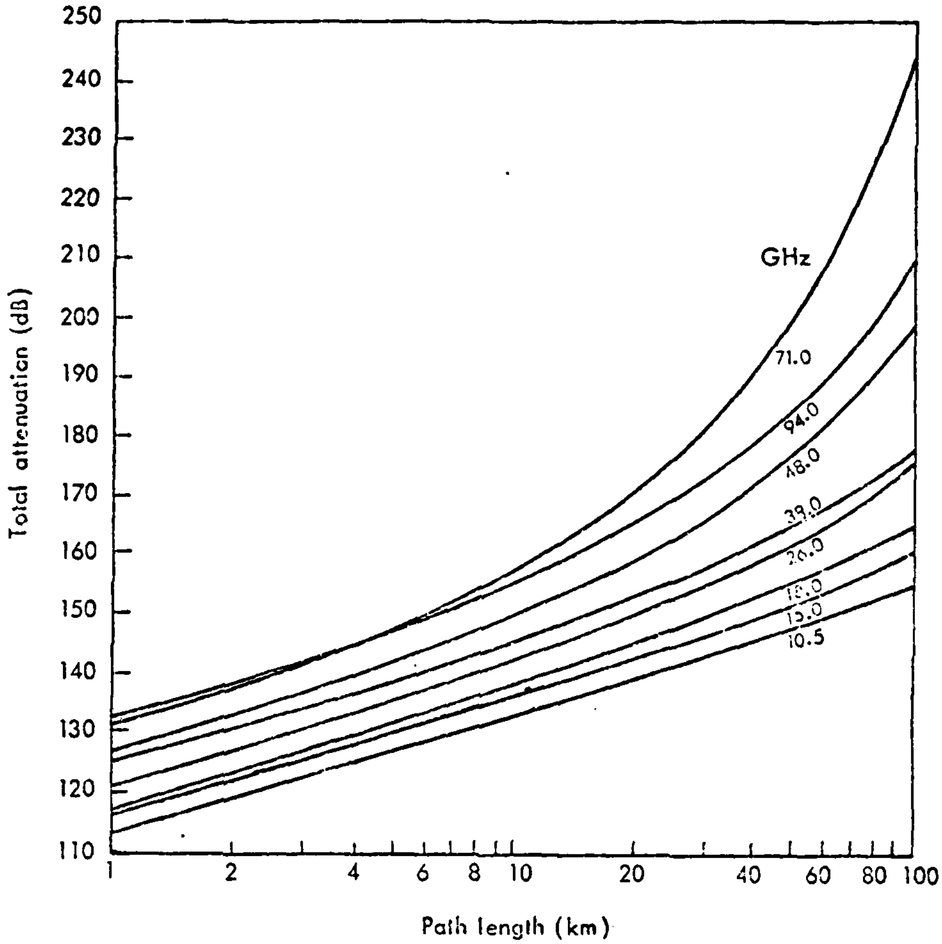


Figure 7. Total attenuation through a clear atmosphere at sea level [Ref. 9].

III. THE STAR TERRAIN MODEL

The STAR (Simulation of Tactical Alternative Responses) ground-air combat model is a computer simulation program developed at the Naval Postgraduate School during 1978-1979. STAR is written in SIMSCRIPT II.5 simulation language. The idea for the STAR terrain representation -- called parametric terrain -- was originally proposed by Major Chris Needels in his 1976 Master of Science Thesis at the Naval Postgraduate School [Ref. 10]. The model as used in this report is the work of Professor James K. Hartman [Ref. 2]. The subroutines that were developed specifically to analyze the MAB radio links are outlined in detail in Appendix A.

The basic function which any terrain representation must provide for a high-resolution combat simulation is, "for any x,y map coordinates on the battlefield, compute the elevation z of the terrain, and the height h of the forest if one exists." The elevation z is generally called the macro terrain.

The parametric terrain model used in STAR involves storing a function f(x,y). The process of determining z for a given x,y then reduces to computing the function z = f(x,y). Parametric terrain has the advantage that the function f can be stored using only a modest amount of computer storage. In addition, the parametric terrain is inherently continuous, so no interpolation is required for smoothing.

The parametric terrain model proposed by Needels represents terrain by modeling individual hill masses. Each hill mass is represented mathematically as a scaled bivariate normal probability density function. This gives a characteristic elliptic bell-shaped hill mass cross section as shown in Figure 8. By varying the parameters, a wide variety of different hill locations, sizes, and shapes can be modeled. By superposing several hill masses, the contour map can be fitted to real map contours remarkably well by using the maximum macro terrain.

In addition to the macro terrain, another factor that influences line-of-sight computations in the STAR model is the presence of forests. Forests in the model are represented by cover ellipses on the ground. Each ellipse has a tree height associated with it, and the forest is thus an elliptical "cylinder" with that fixed height above the ground. Actual forests with non-elliptical shapes and non-constant heights can be approximated by combining several overlapping ellipses. The tree height at a given point x,y is the maximum tree height for all the forest ellipses containing the point x,y.

Figures 11, 12, and 13 show the terrain model on which all computations have been performed. They are a 10 by 30 km section of terrain near the town of Hunfeld, West Germany. Hunfeld is located near the East German border in the Fulda Gap region of central West Germany.

The map symbols that resemble capital Y's represent forested areas. The contour lines are drawn every 10 meters with

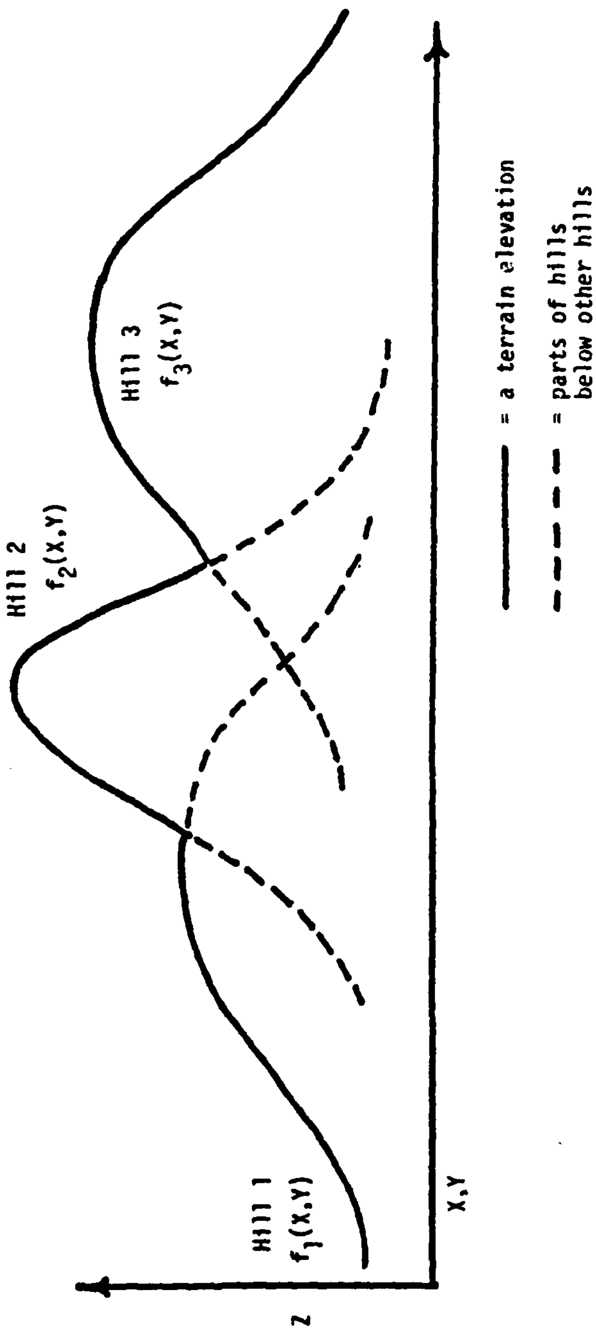


Figure 8. MACRO terrain is the maximum over all the hill masses.

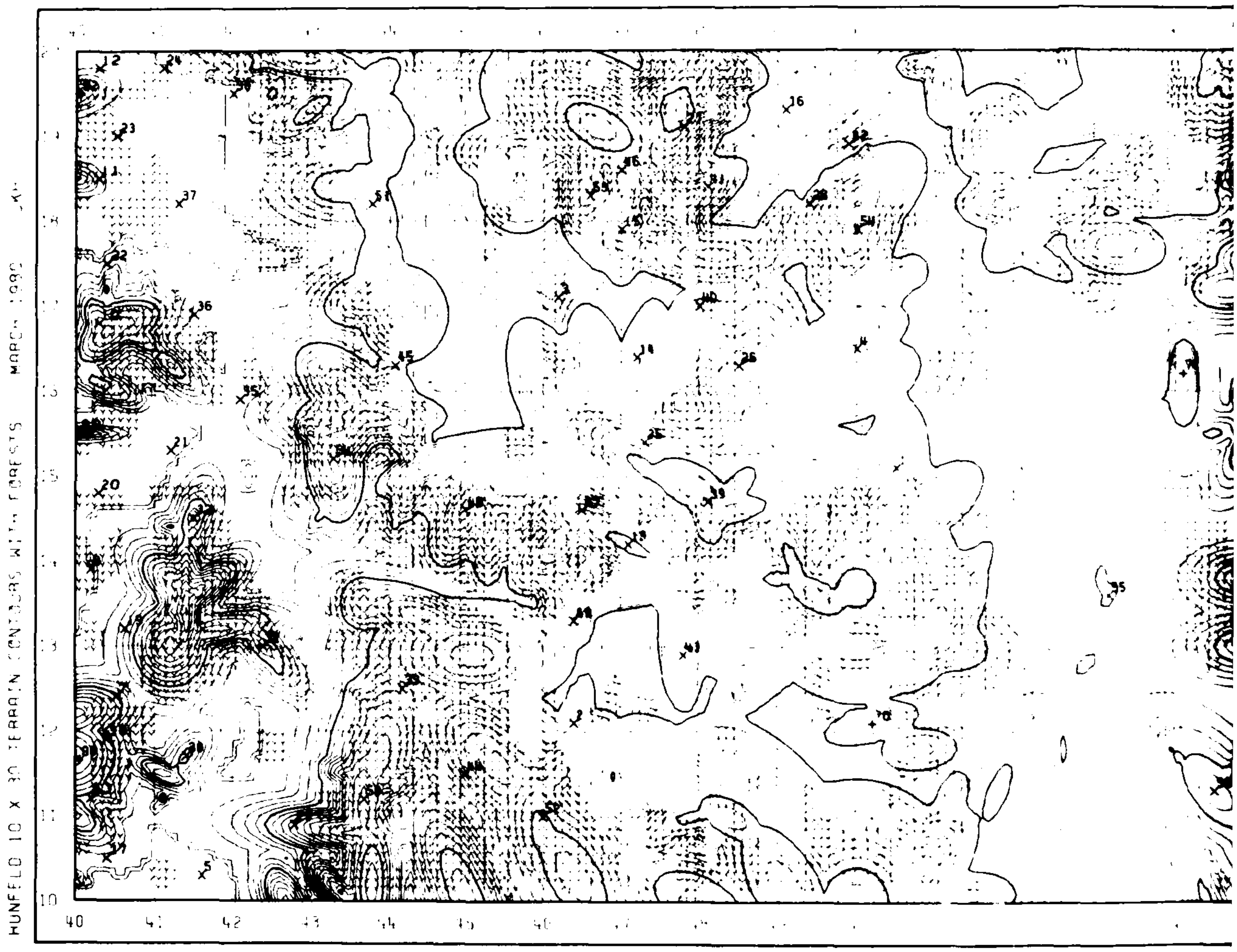
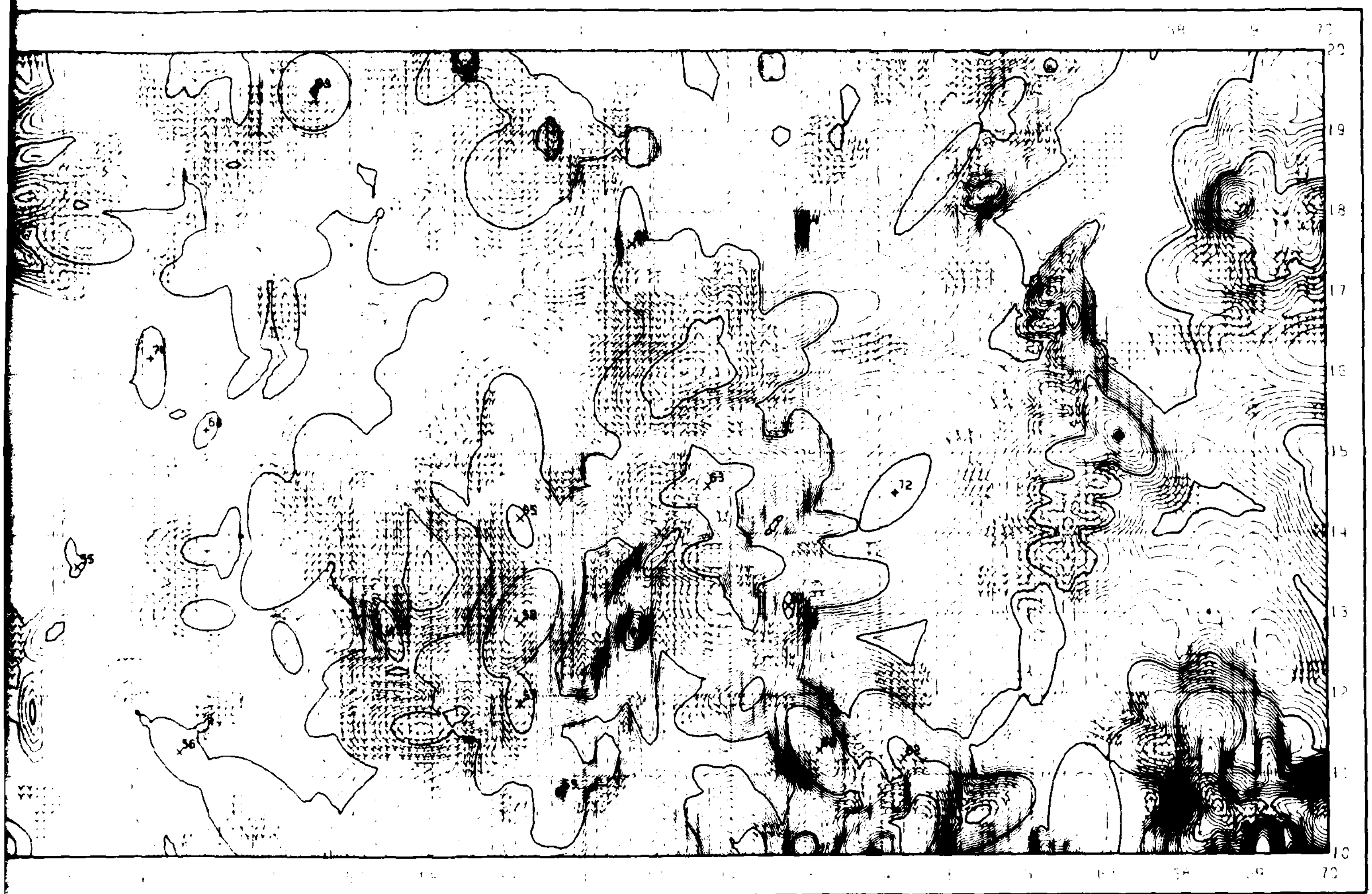


Figure 11. MAB Unit locations for the first set of data points.



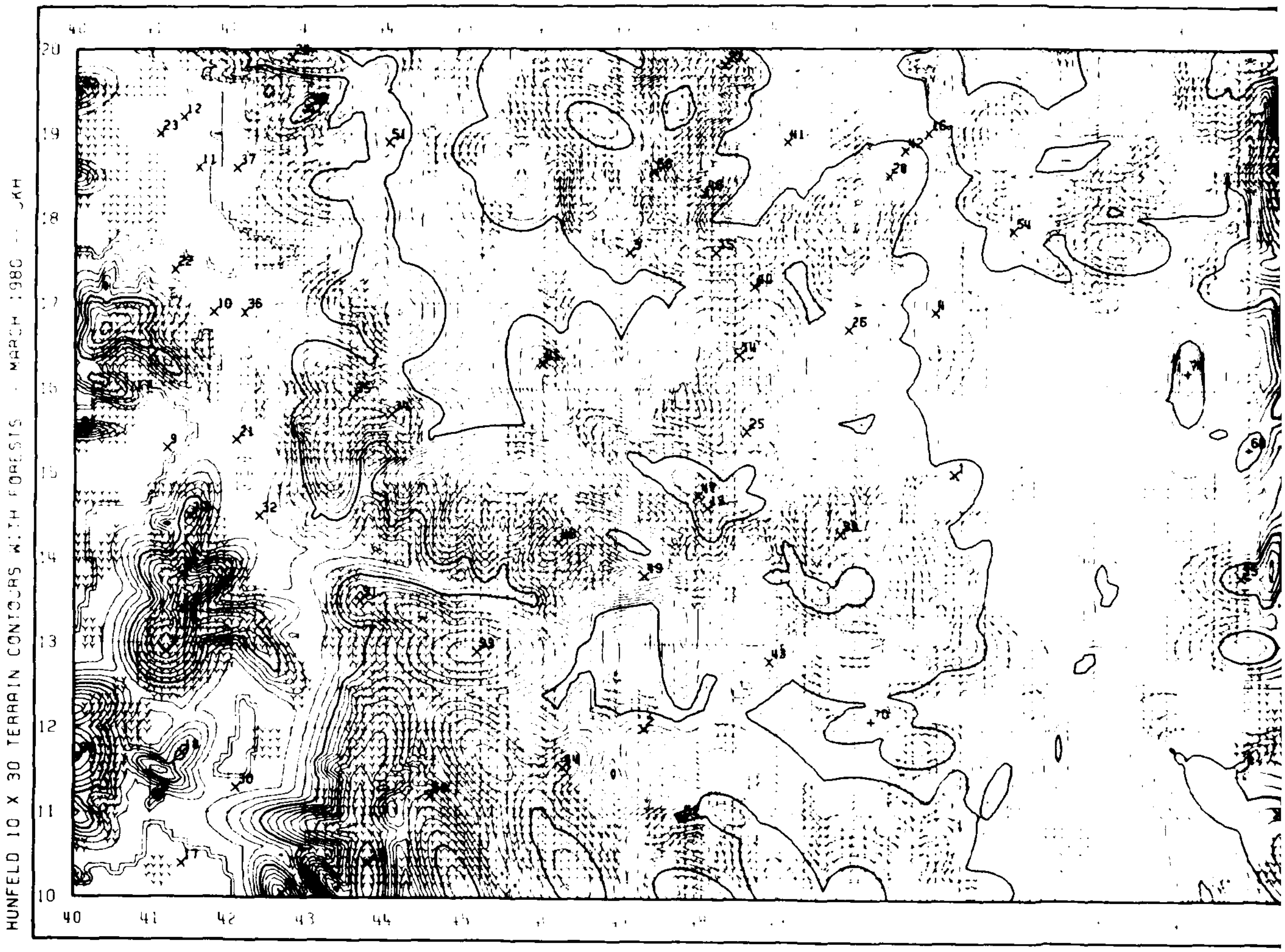
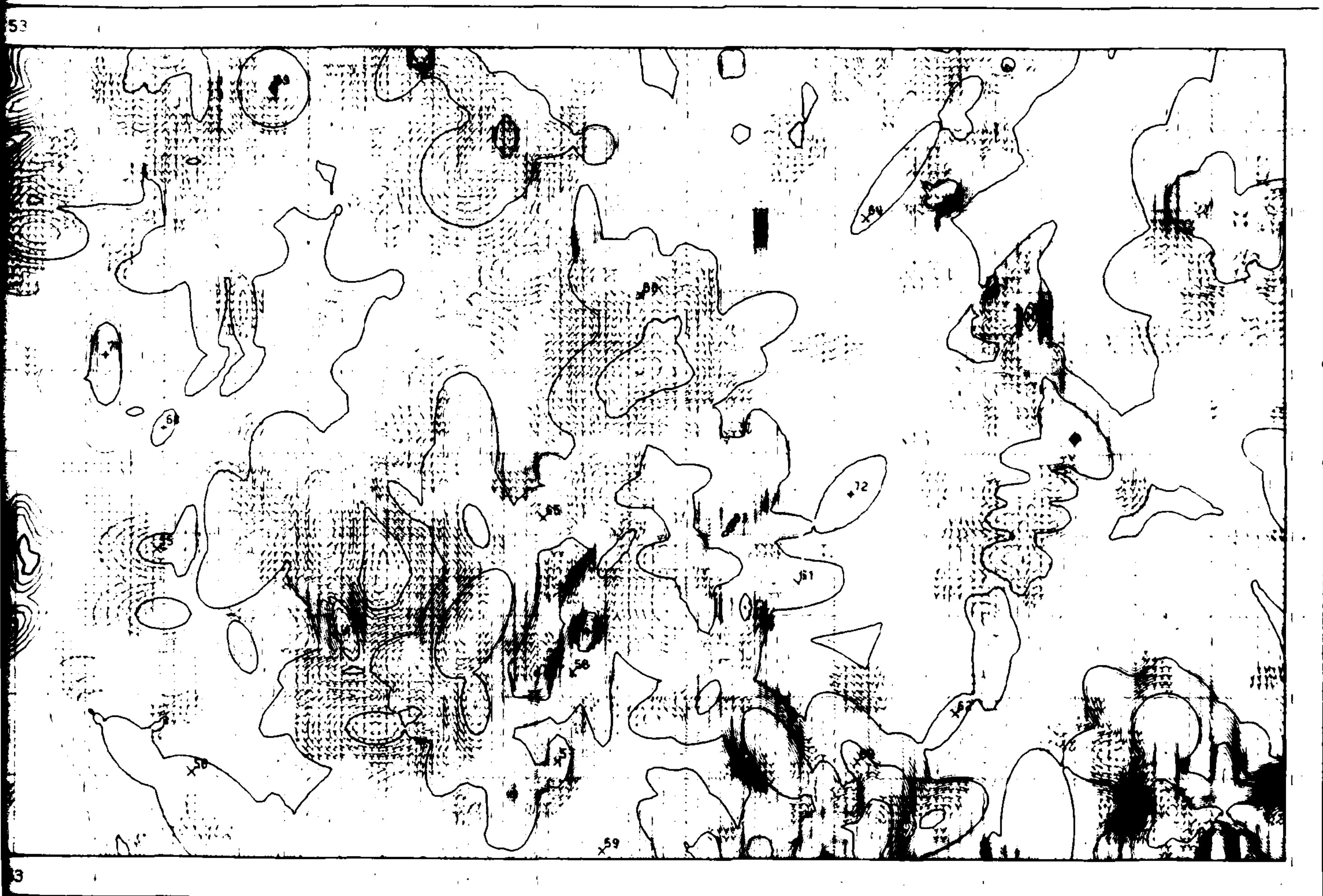


Figure 12. MAB Unit locations for the second set of data points.



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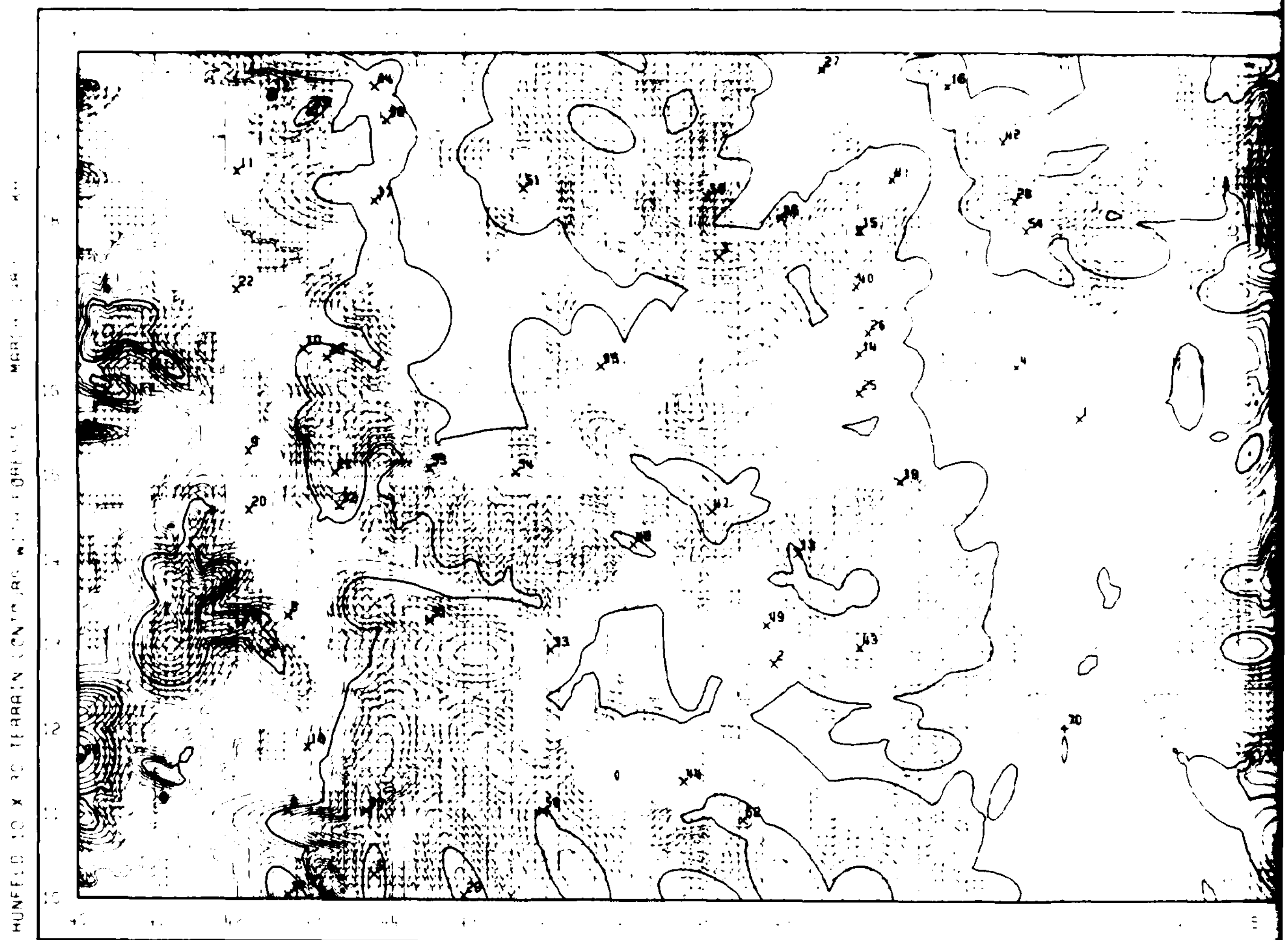
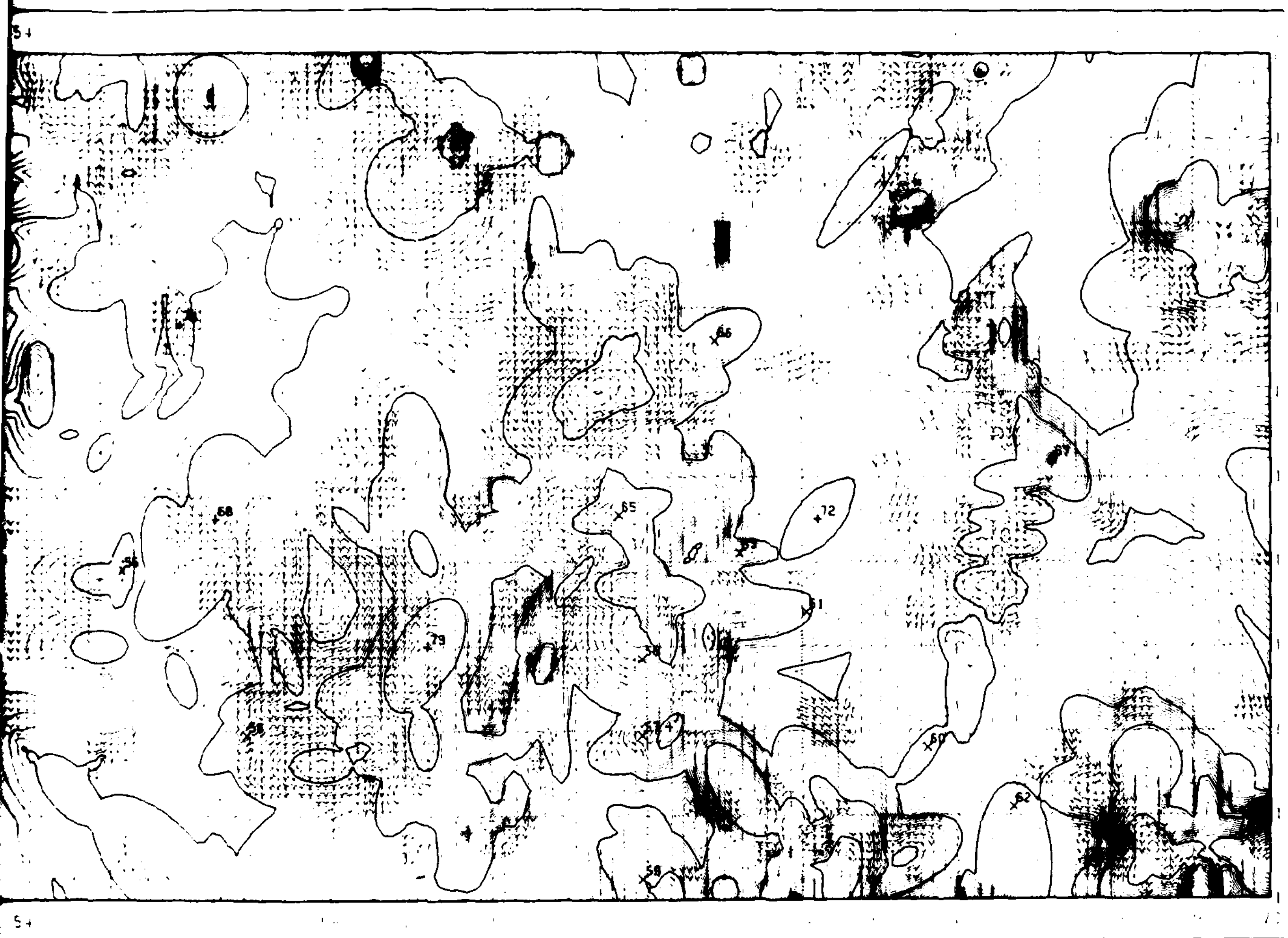


Figure 13. MAB Unit locations for the third set of data points.



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100-meter contour lines accented. Grid lines in both the horizontal and vertical directions are every 1000 meters. The valley located at 41000 19000 has an elevation of 230 meters above sea level. The other two major valleys, located at 53000 15000 and 76000 19000, have elevations of 250 and 280 meters, respectively. The terrain represented in the model is highly forested and very irregular and is representative of many areas of the world.

The use of the STAR model has been simplified by the subroutine RES.TERR developed by Professor Hartman. This subroutine is called by the main program first and is set up to dynamically reserve and dimension the various arrays so that core requirements are minimized. The input to RES.TERR is parameter information on the hill masses and forest ellipses. This parameter information is currently stored on disk.

To use the model all that is needed is to read in two ten-digit grid coordinates and assign them to the variables XA.LS, YA.LS, XB.LS and YB.LS. The variable XA.LS is the five-digit x coordinate of the first point A and YA.LS is the five-digit y coordinate. Now the macro terrain elevation can be found by calling subroutine ELEV, or the height of the trees at point A can be found by calling the subtroutine TREES.

To calculate the line-of-sight (LOS), the following information must be available for both points A and B:

(1) The x and y coordinates on the battlefield expressed as XA.LS and YA.LS.

(2) The macro terrain elevation (TMACA.LS) computed from the ELEV subroutine.

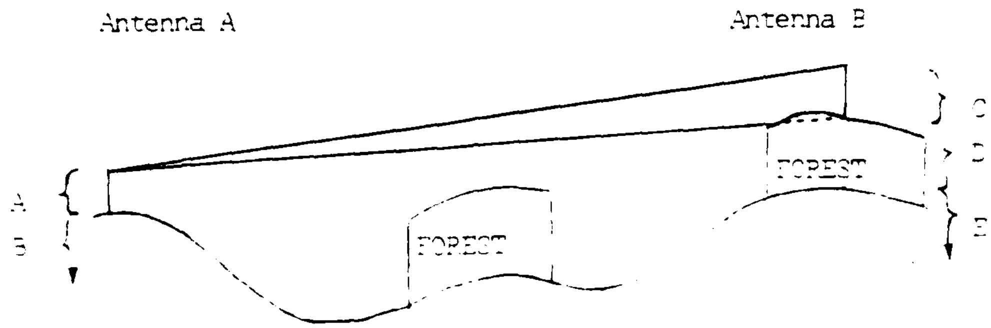
(3) A micro terrain offset (TMICA.LS) of + or - from the macro terrain. The offset is used to place some of the antennas above the surrounding forest.

(4) The last piece of information that is needed is the size of the antenna (SIZE.LS), which is specified as three meters in this report.

Now the LOS subroutine can be called which will return the percent visible of antenna B, i.e., the fraction of antenna B that can be seen from the top of antenna A. This is depicted in Figure 9 where point A's antenna is mounted on top of the radio and point B's antenna is mast mounted.

The preceding paragraphs provide an overview of Professor Hartman's report. Anyone wishing to use the STAR model should become familiar with Ref. 2 before proceeding.

Four routines were written as part of this thesis specifically to analyze the MAB's radio links. They are MAIN, REPORT.PRINT, LPI and FOREST. The purpose of the MAIN program is to determine if a radio transmission path exists between points A and B, at the specified high frequency, at the specified low frequency, or if no path exists at all. The program defines a low frequency (FREQ.L) and high frequency (FREQ.H). The maximum allowable loss between points A and B, as given in Chapter I, is then specified. The line-of-sight is specified as being from A to B (LATOB.LS=1).



A - SIZEA.LS

B - TMACA.LS

C - SIZEB.LS

D - TMICB.LS

E - TMACB.LS

Figure 9. A Line-of-Sight Exists if the Top of Antenna A Can See the Top of Antenna B.

All of the points to be analyzed are read in at once with the x coordinate first followed by the y coordinate, the node number, the printing symbol code, and the "Mobility Factor."[2] Then each pair of points is analyzed. Since all pairs of points make up a symmetric matrix, only the upper half of the matrix is analyzed. The offset (TMICA.LS) is initially set to zero, but it can be changed to the tree height if the mobility factor is "1."

The macro terrain elevation is found along with the tree height at each pair of points. Antenna heights are also computed and some redefining is done in preparation for the first call of the LOS subroutine. The first call of LOS is done over a terrain model that is void of trees. If a line-of-sight exists over the ground then the forest ellipses are reinstated and another line-of-sight is shot. The loss for free-space and the loss associated with Bullington's equation are both computed and the greater loss is used. If a line-of-sight exists over the ground but not over the trees, then the subroutine FOREST is called. The output of FOREST is the amount of forests that lie between points A and B.

Now the total losses between A and B can be computed, since it is a function of the distance, frequency and amount of trees that intersect the line-of-sight. For each link, analysis is

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[2] The Mobility Factor describes the unit's ability to erect a large antenna and is described in Chapter [illegible].

done to determine if the link can operate at the high frequency, and then at the low frequency. For links that exist, the fading margin is given as the number of dBs above the required 11 dB, for a required $P_e = 10^{-6}$. If neither frequency produces a favorable margin, then the link is discarded and another pair of points (A,B) is looked at. For links that do exist, the distance between the two points is stored in matrix form for both (A,B) and (B,A). The distance is stored as a truncated number if the link is being carried by the higher frequency, and point one is added to the distance if it is being carried by the lower frequency.

Next, the matrix of distance is sorted and the five nearest neighbors to each point are displayed in table form. The nearest neighbor would appear in the table as 10 if it was accessible at the higher frequency and 11 if it was accessible by the lower frequency. Other valid entries in the table are 20, 21, 30, 31, 40, 41, 50, and 51.

The subroutine REPORT.PRINT prints out the contents of the matrix that contains the listing of the five nearest neighbors. It prints out the matrix in two separate formats. The first format is larger and easier to work with, while the second format is compatible with an 8-1/2" x 11" piece of paper.

The subroutine LPI determines the signal-to-noise ratio that an enemy listening post would receive if it used an antenna with a gain of 3.8 dB. This subroutine follows the

same procedures as the MAIN program except its output is the SNR and not the fading margin that the main program calculates.

The FOREST subroutine was designed to calculate the amount of forests that lie between points A and B. The routine checks the heights of the trees every 1/100 of the distance between the two end points. Every time that the height of the trees intersects the line-of-sight, it adds one more percent to its counter. When the routine is completed, it has a number that expresses the percent of the distance that the tree height exceeded the line-of-sight. This percent is returned to the main program where the depth of the forest in meters is determined by multiplication by the distance.

IV. UNIT LOCATIONS

On the battlefield are positioned sixty-six units that comprise the Marine Amphibious Brigade (MAB). There is also one point that represents an external connection with higher headquarters plus seven repeater stations. In addition to the one special point, any node near the boundary of the MAB could be used as an external connection point. These seventy-four points and their relative positions were furnished by Ref. 11. In their original form they had a frontage of 16 km and a depth of 26 km. Position number 1 was the Regimental Headquarters and also grid center for the map. All other positions were given coordinates relative to the Regimental Headquarters as shown in Table 1.

Since the STAR terrain model map of Hunfeld, West Germany, was only 10 km wide by 30 km in depth, there existed a need to decrease the frontage of the MAB. Each unit's lateral distance from grid center was decreased by 5/8 and it was given coordinates that made it compatible with the Hunfeld map. Table 2 lists the new coordinates and Figure 10 shows the relative positions of all points on the map.

The reduced frontage of the MAB does make connectivity easier on this terrain model because of the reduction in the average amount of trees between nodes. Whether or not this frontage is realistic is a question that cannot be answered without knowledge of the density of the enemy units. It is

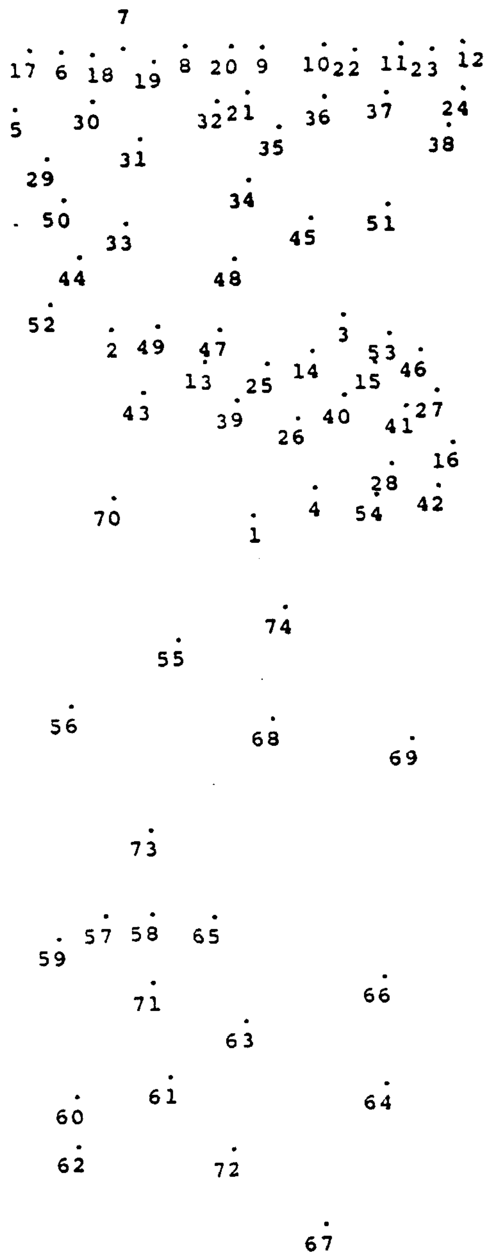

Figure 10. MAB Unit locations for the first set of data points, nodes.

worth noting that the 16 km front was for a situation in southern California where the lack of trees would have made the connectivity easier.

The points went through another transition when they were actually placed on the map. A term was used, called "antenna sight selection," whereby each antenna was placed within 200 - 300 meters from the unit's location in an area that was conducive to radio frequency communications. This kept the antennas out of the bottom of ravines and also prevented enemy direction finding systems from pinpointing unit locations, since the antenna and unit were not colocated.

A list of final coordinates is given as Table 3 along with their "Mobility Factor." Each unit has been given a mobility factor of either one or zero. If a unit has a mobility factor of zero, then it is assumed to be in almost constant motion and unable to erect an external antenna. Its antenna is defined as being three meters above the ground. If a unit has a mobility factor of one, then it is using an external antenna that is either three meters above the ground when the unit is in a clearing, or three meters above the forest when the unit is in a forest. Mobility factors of one have been given to units of battalion size and larger.

After all the units of the MAB were analyzed for connectivity in the first set of positions, described in Table 3 and Figure 11, they were moved back from the FEBA. The FEBA is near the grid line 40000. They were again analyzed in the second set of positions, described in Table 4 and

Figure 12, and moved again. The final set of positions used is described in Table 5 and Figure 13. Each time that the set of units was moved, their relative positions to one another were maintained. This was accomplished by requiring each unit to move backward into the next adjoining grid square. The units were permitted, however, to find an optimum position in that adjoining grid square. The movement of the repeaters, nodes 68 through 74, were not as strictly controlled as the units. When the units were moved into their second set of positions, the repeaters were not moved. The repeater positions were changed when the units were moved into the third set of positions. They were positioned on key terrain in positions relative to where they were at the start of the problem. Thus, their role of bridging the gap between distant units was again reinstated.

Three enemy listening posts were established along the FEBA and they were used to analyze what units could be intercepted. Analysis of RF interception is discussed in Chapter V.

Table 1. Marine Anphibious Brigade (MAB) Unil locations, all points relative to the infantry regiment.

NODE	NAME	LOCATION	
1	Inf Regt	000	000
2	Inf Bn	-040	040
3	Inf Bn	040	040
4	Inf Bn	030	003
5	TACP 1	-074	084
6	TACP 2	-063	096
7	TACP 3	-040	097
8	TACP 4	-046	097
9	TACP 5	007	096
10	TACP 6	027	097
11	TACP 7	051	097
12	TACP 8	073	094
13	TACP 9	-009	027
14	TACP 10	024	027
15	TACP 11	046	028
16	TACP 12	062	010
17	FAAD 1	-074	095
18	FAAD 2	-045	097
19	FAAD 3	-028	092
20	FAAD 4	-006	096
21	FAAD 5	005	089
22	FAAD 6	034	096
23	FAAD 7	060	094

NODE	NAME	LOCATION
24	FAAD 8	074 086
25	FAAD 9	004 027
26	FAAD 10	025 018
27	FAAD 11	061 023
28	FAAD 12	052 007
29	Inf Co A	-073 069
30	Inf Co B	-055 083
31	Inf Co C	-029 077
32	Inf Co D	-008 081
33	Engr 1	-025 060
34	Engr 2	019 063
35	Inf Co E	011 079
36	Inf Co F	030 083
37	Inf Co G	050 083
38	Inf Co H	070 077
39	Inf Co I	-003 021
40	Inf Co K	032 023
41	Inf Co L	050 019
42	Inf Co M	059 003
43	Arty Bn	-026 022
44	Arty Bty A	-047 051
45	Arty Bty B	031 057
46	Arty Bty C	056 032

NODE	NAME	LOCATION
47	Arty Bty D	-003 037
48	LAAM	-006 051
49	Armor Bn	-018 032
50	Armor Co A	-041 062
51	Armor Co B	046 062
52	Mortar 1	-049 037
53	Mortar 2	050 039
54	Mortar 3	039 005
55	MAB (Fwd)	-006 -027
56	Helo Sqdn	-039 -037
57	MAG	-034 -085
58	TACC	-027 -091
59	Sqdn (VMF)	-047 -093
60	Sqdn (VMA)	-068 -133
61	TAOC	-043 -134
62	MATCU	-063 -143
63	MAB (Rear)	000 -114
64	LSG	044 -122
65	LSU 1	-012 -086
66	LSU 2	027 -093
67	External	017 -157
68	Repeater 1	-043 079
69	Repeater 2	-026 000

NODE	NAME	LOCATION
70	Repeater 3	-019 -054
71	Repeater 4	017 -055
72	Repeater 5	027 -110
73	Repeater 6	-024 -060
74	Repeater 7	019 -014

Table 2. MAB Unit locations, first set of data points

[illegible]	NAME	LOCATION
1	Inf Regt	50300 15000
2	Inf Bn	46100 12200
3	Inf Bn	46200 17100
4	Inf Bn	50000 16500
5	TACP 1	41600 10300
6	TACP 2	40200 11200
7	TACP 3	40500 12400
8	TACP 4	40200 13900
9	TACP 5	40200 15700
10	TACP 6	40300 16800
11	TACP 7	40300 18500
12	TACP 8	40300 19800
13	TACP 9	47400 14000
14	TACP 10	47500 16500
15	TACP 11	47300 17100
16	TACP 12	49100 19300
17	FAAD 1	40400 10500
18	FAAD 2	40500 12000
19	FAAD 3	40600 13200
20	FAAD 4	40300 14800
21	FAAD 5	41200 15300
22	FAAD 6	40400 17500
23	FAAD 7	40500 19000

[illegible]	[illegible]	41100	19800
25	FAAD 9	47300	15400
26	FAAD 10	48500	16300
27	FAAD 11	47800	19100
28	FAAD 12	49400	18200
29	Inf Co A	42800	10800
30	Inf Co B	41500	11500
31	Inf Co C	42400	12800
32	Inf Co D	41800	14300
33	Engr 1	44000	12500
34	Engr 2	43800	14900
35	Inf Co E	42100	15900
36	Inf Co F	41500	16900
37	Inf Co G	41300	18200
38	Inf Co H	42000	19500
39	Inf Co I	48100	14700
40	Inf Co K	48000	17000
41	Inf Co L	48200	18000
42	Inf Co M	49100	18900
43	Arty Bn	48000	12400
44	Arty Bty A	45000	11500
45	Arty Bty B	44400	16200
46	Arty Bty C	47000	18600

[illegible]	[illegible]	46500	14600
[illegible]	LAAM	45100	14400
[illegible]	Armor [illegible]	46900	13200
[illegible]	Armor [illegible]	44000	11200
[illegible]	Armor [illegible]	43900	17700
[illegible]	Mortar 1	46500	11200
[illegible]	Mortar 2	46300	18000
[illegible]	Mortar 3	49700	17400
[illegible]	MAB (Fwd)	53000	14500
[illegible]	Helo Sqdn	54000	11100
57	MAG	5-000	11600
58	TACC	59500	12400
59	Sqdn (VMF)	59700	10300
60	Sqdn (VMA)	63600	10500
61	TAOC	63500	13000
62	MATCU	64500	11300
63	MAB (Rear)	61800	15000
64	LSG	62300	19400
65	LSU 1	59000	13900
66	LSU 2	59700	17700
67	External	66000	17000
68	Repeater 1	55000	15000
69	Repeater 2	56500	19500

	[illegible]	12[illegible]
[illegible]	60500	12500
[illegible]	64000	1450
[illegible]	[illegible]	1250
[illegible]	540[illegible]	160[illegible]

[illegible] the first set of data points with antenna [illegible]

1	50500	15100
1	46400	12100
1	46200	17100
[illegible]	50000	16500
[illegible]	41600	10300
[illegible]	40200	11200
[illegible]	40500	12400
[illegible]	40200	13900
[illegible]	40200	15500
[illegible]	40300	16600
[illegible]	40300	18500
[illegible]	40300	19800
[illegible]	47100	14200
[illegible]	47200	16400
[illegible]	47[illegible]00	17900
[illegible]	49100	19300
[illegible]	40400	10500
[illegible]	40400	11900
[illegible]	40600	13200
[illegible]	40300	14800
[illegible]	41200	15300
[illegible]	4[illegible]400	17500
[illegible]	[illegible]	19000

NODE	NAME	MOBILITY	LOCATION	
24	FAAD 8	0	41100	19800
25	FAAD 9	0	47300	15400
26	FAAD 10	0	48500	16300
27	FAAD 11	0	47800	19100
28	FAAD 12	0	49400	18200
29	Inf Co A	0	42800	10900
30	Inf Co B	0	41400	11700
31	Inf Co C	0	42400	13000
32	Inf Co D	0	41500	14500
33	Engr 1	1	44200	12500
34	Engr 2	1	43300	15200
35	Inf Co E	0	42100	15900
36	Inf Co F	0	41500	16900
37	Inf Co G	0	41300	18200
38	Inf Co H	0	42000	19500
39	Inf Co I	0	48100	14700
40	Inf Co K	0	48000	17000
41	Inf Co L	0	48100	18400
42	Inf Co M	0	49900	18900
43	Arty Bn	1	47800	12900
44	Arty Bty A	1	45000	11500
45	Arty Bty B	1	44100	16300
46	Arty Bty C	1	47000	18600

NODE	NAME	MOBILITY	LOCATION	
47	Arty Btry D	1	46500	14600
48	LAAM	1	45000	14600
49	Armor Bn	1	46400	13300
50	Armor Co A	1	43700	11200
51	Armor Co B	1	43800	18200
52	Mortar 1	1	46000	11000
53	Mortar 2	1	46600	18300
54	Mortar 3	1	50000	17900
55	MAB (Fwd)	1	53200	13600
56	Helo Sqdn	1	54600	11300
57	MAG	1	59200	11900
58	TACC	1	59200	12900
59	Sqdn (VMF)	1	59700	10800
60	Sqdn (VMA)	1	63200	11300
61	TAOC	1	62800	13100
62	MATCU	1	64300	11200
63	MAB (Rear)	1	61700	14600
64	LSG	1	63000	17800
65	LSU 1	1	59200	14200
66	LSU 2	1	60700	17600
67	External	1	66000	16600
68	Repeater 1	1	55000	15300
69	Repeater 2	1	56500	19500

NODE	NAME	MOBILITY	LOCATION
70	Repeater 3	1	50200 12100
71	Repeater 4	1	60700 12800
72	Repeater 5	1	64200 14500
73	Repeater 6	1	57500 12800
74	Repeater 7	1	54190 16200

Table 4. MAB Unit locations, the second set of data points with antenna sight selection, and mobility factor.

NODE	NAME	MOBILITY	LOCATION
1	Inf Regt	1	51250 15000
2	Inf Bn	1	47300 12000
3	Inf Bn	1	47100 17600
4	Inf Bn	1	51000 16900
5	TACP 1	0	42700 10050
6	TACP 2	0	41100 11200
7	TACP 3	0	41200 12900
8	TACP 4	0	41400 13800
9	TACP 5	0	41200 15300
10	TACP 6	0	41800 16900
11	TACP 7	0	41600 18600
12	TACP 8	0	41400 19200
13	TACP 9	0	48100 14600
14	TACP 10	0	48500 16400
15	TACP 11	0	48200 17600
16	TACP 12	0	50900 19000
17	FAAD 1	0	41400 10400
18	FAAD 2	0	41400 11700
19	FAAD 3	0	41200 13000
20	FAAD 4	0	41500 14500
21	FAAD 5	0	42100 15400
22	FAAD 6	0	41300 17400
23	FAAD 7	0	41100 19000

NODE	NAME	MOBILITY	LOCATION	
24	FAAD 8	0	42300	19900
25	FAAD 9	0	48600	15500
26	FAAD 10	0	49900	16700
27	FAAD 11	0	48300	19800
28	FAAD 12	0	50400	18500
29	Inf Co A	0	43800	10400
30	Inf Co B	0	42100	11300
31	Inf Co C	0	43700	13500
32	Inf Co D	0	42400	14500
33	Engr 1	1	45200	12900
34	Engr 2	1	44100	15700
35	Inf Co E	0	43600	15900
36	Inf Co F	0	42200	16900
37	Inf Co G	0	42100	18600
38	Inf Co H	0	43000	19300
39	Inf Co I	0	49800	14300
40	Inf Co K	0	48700	17200
41	Inf Co L	0	49100	18900
42	Inf Co M	0	50600	18800
43	Arty Bn	1	48900	12800
44	Arty Bty A	1	46250	11550
45	Arty Bty B	1	45990	16300
46	Arty Bty C	1	48050	18300

NODE	NAME	MOBILITY	LOCATION	
47	Arty Bty D	1	47990	14750
48	LAAM	1	46200	14200
49	Armor Bn	1	47300	13800
50	Armor Co A	1	44600	11200
51	Armor Co B	1	44050	18900
52	Mortar 1	1	47800	10950
53	Mortar 2	1	47400	18550
54	Mortar 3	1	51990	17850
55	MAB (Fwd)	1	54900	13800
56	Helo Sqdn	1	55400	11050
57	MAG	1	60300	11200
58	TACC	1	60700	12800
59	Sqdn (VMF)	1	60900	10100
60	Sqdn (VMA)	1	64300	11200
61	TAOC	1	63500	13400
62	MATCU	1	65600	11800
63	MAB (Rear)	1	62600	14100
64	LSG	1	64400	17900
65	LSU 1	1	60100	14200
66	LSU 2	1	61400	16950
67	External	1	66600	16700
68	Repeater 1	1	55000	15300
69	Repeater 2	1	56500	19500

NODE	NAME	MOBILITY	LOCATION	
[illegible]	Repeater 3	1	50200	12100
71	Repeater 4	1	60700	12800
72	Repeater 5	1	64200	14500
73	Repeater 6	1	57500	12800
74	Repeater 7	1	54190	16200

Table 5. MAB Unil locations, the third set of data points with antenna sight selection, and mobility factor.

[illegible]	[illegible]	[illegible]	[illegible]	
1	Inf Hqt	1	52800	15700
2	Inf Bn	1	48900	12800
3	Inf Bn	1	48200	17600
4	Inf Bn	1	51990	16300
5	TACP 1	0	43800	10300
6	TACP 2	0	42700	11050
7	TACP 3	0	42450	12900
8	TACP 4	0	42700	13350
9	TACP 5	0	42200	15300
10	TACP 6	0	42900	16500
11	TACP 7	0	42050	18600
12	TACP 8	0	42500	19500
13	TACP 9	0	49200	14100
14	TACP 10	0	49990	16450
15	TACP 11	0	49990	17900
16	TACP 12	0	51100	19600
17	FAAD 1	0	42700	10050
18	FAAD 2	0	42950	11800
19	FAAD 3	0	42100	13250
20	FAAD 4	0	42200	14600
21	FAAD 5	0	43300	15050
22	FAAD 6	0	42050	17200
23	FAAD 7	0	42990	19300

NODE	NAME	MOBILITY	LOCATION
24	FAAD 8	0	43800 19600
25	FAAD 9	0	49990 15990
26	FAAD 10	0	50100 16700
27	FAAD 11	0	49500 19800
28	FAAD 12	0	51950 18250
29	Inf Co A	0	44950 10050
30	Inf Co B	0	43700 11050
31	Inf Co C	0	44500 13300
32	Inf Co D	0	43350 14650
33	Engr 1	1	46050 12950
34	Engr 2	1	45600 15050
35	Inf Co E	0	44500 15100
36	Inf Co F	0	43200 16400
37	Inf Co G	0	43800 18250
38	Inf Co H	0	43950 19200
39	Inf Co I	0	50500 14950
40	Inf Co K	0	49950 17250
41	Inf Co L	0	50400 18500
42	Inf Co M	0	51800 18950
43	Arty Bn	1	49990 12990
44	Arty Bty A	1	47750 11400
45	Arty Bty B	1	46700 16300
46	Arty Bty C	1	48990 18050

NODE	NAME	MOBILITY	LOCATION	
47	Arty Bty D	1	48100	14600
48	LAAM	1	47100	14200
49	Armor Bn	1	48800	13250
50	Armor Co A	1	45950	11050
51	Armor Co B	1	45700	18400
52	Mortar 1	1	48500	10950
53	Mortar 2	1	48050	18300
54	Mortar 3	1	52100	17900
55	MAB (Fwd)	1	55300	13900
56	Helo Sqdn	1	56950	11950
57	MAG	1	61950	11950
58	TACC	1	61950	12850
59	Sqdn (VMF)	1	61950	10250
60	Sqdn (VMA)	1	65600	11800
61	TAOC	1	64050	13400
62	MATCU	1	66700	11100
63	MAB (Rear)	1	63200	14100
64	LSG	1	65100	17900
65	LSU 1	1	61650	14550
66	LSU 2	1	62900	16600
67	External	1	67200	15200
68	Repeater 1	1	56550	14500
69	Repeater 2	1	59600	18900

NODE	NAME	MOBILITY	LOCATION	
70	Repeater 3	1	52600	12050
71	Repeater 4	1	62300	12050
72	Repeater 5	1	64200	14500
73	Repeater 6	1	59250	12990
74	Repeater 7	1	56100	16800

V. CONNECTIVITY

A. GENERAL

The operational characteristics of the radio frequency band have a major impact on the connectivity of the MAB's packet radio system. The lowest and highest frequencies which can be used for a packet radio system are determined primarily by considerations of bandwidth and propagation link loss. Practical, cost-effective radio equipment is difficult to find if the ratio of RF bandwidth to RF center frequency is much larger than about 15%. With a 16 kbs data rate and a 32 kHz RF bandwidth, this puts the lower bound of RF center frequencies at about 200 kHz. With pseudonoise modulation, the lowest usable frequency will be multiplied by the "spreading factor."

The upper limits of usable frequencies are determined by total link losses. As the operating frequency rises above about 10 GHz, absorptive losses due to the atmosphere, rain, and foliage penetration rapidly increase, and the resulting range is reduced accordingly.

B. SHF CONNECTIVITY

For a center frequency of 40 GHz and a percent reliability of 99.9%, Figures 6a and 7 give the maximum single hop distance such that the path loss does not exceed 141 dB as described in Chapter I.

$$141 \text{ dB} \geq [(\frac{4\pi d}{\lambda})^2 \cdot L_{O_2 - H_2O}]_{dB} + (L_{Rain})_{dB}$$

$$141 \text{ dB} \geq 132 \text{ dB} + 8 \text{ dB}$$

For a maximum distance of 2.5 km a link can exist in the absence of any trees. From Figure 14 for a frequency of 40 GHz the attenuation due to trees is between 2 and 5 dB per meter of forest. At this frequency, a single tree could produce almost 50 dB of attenuation. Therefore, Figure 15 displays all links that are less than 2.5 km and whose line-of-sight is not obstructed by any trees. Only 53% of the units have a connection, and these connections are broken down into eight disjointed sets. It is obvious at 40 GHz that connectivity does not exist.

If 20 GHz is used as the center frequency with the same percent reliability, Figures 6a and 7 give the maximum single hop distance as 5 km. From Figure 14 for a frequency of 20 GHz, the attenuation due to trees is still about 2 to 5 dB per meter. Figure 16 displays all the links that are less than 5 km and whose line-of-sight is not obstructed by any trees. This is a noticeable improvement in that 69% of the units have a connection, but connectivity does not exist since there is a limited capability to pass traffic from the forward units to the units in the rear. A loss of key nodes

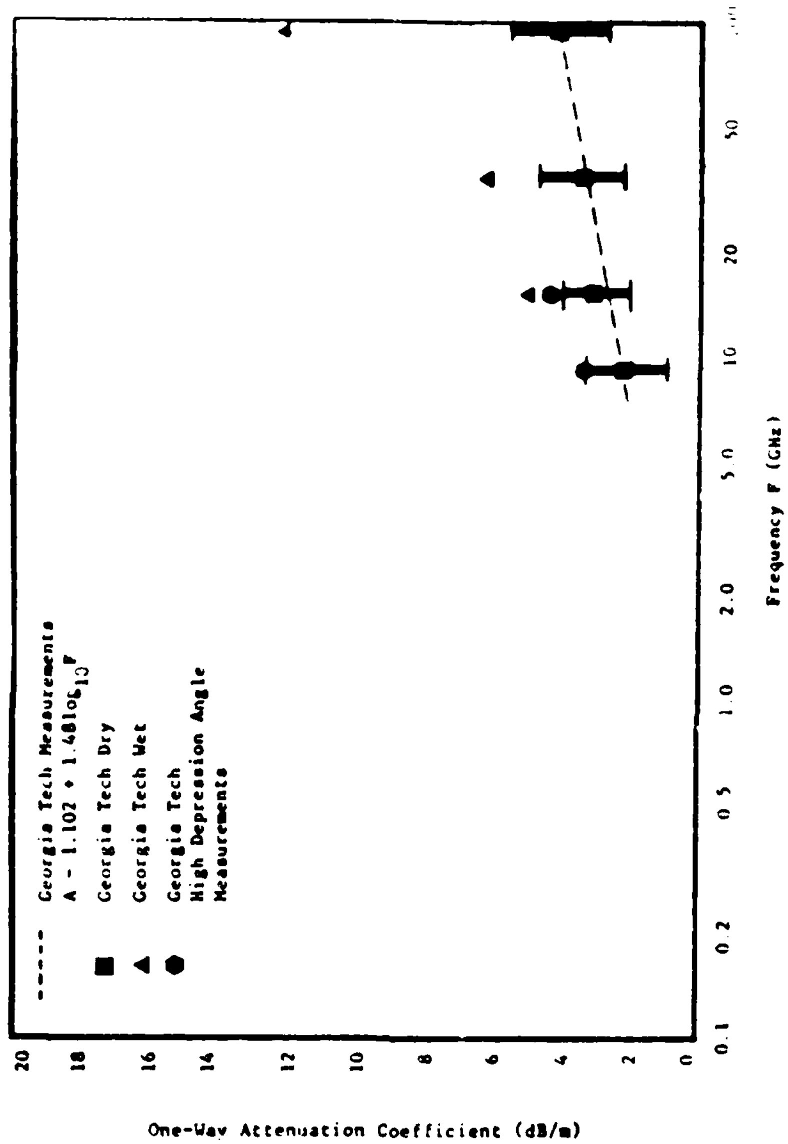

Figure 14. Attenuation due to foliage [Ref. 12].

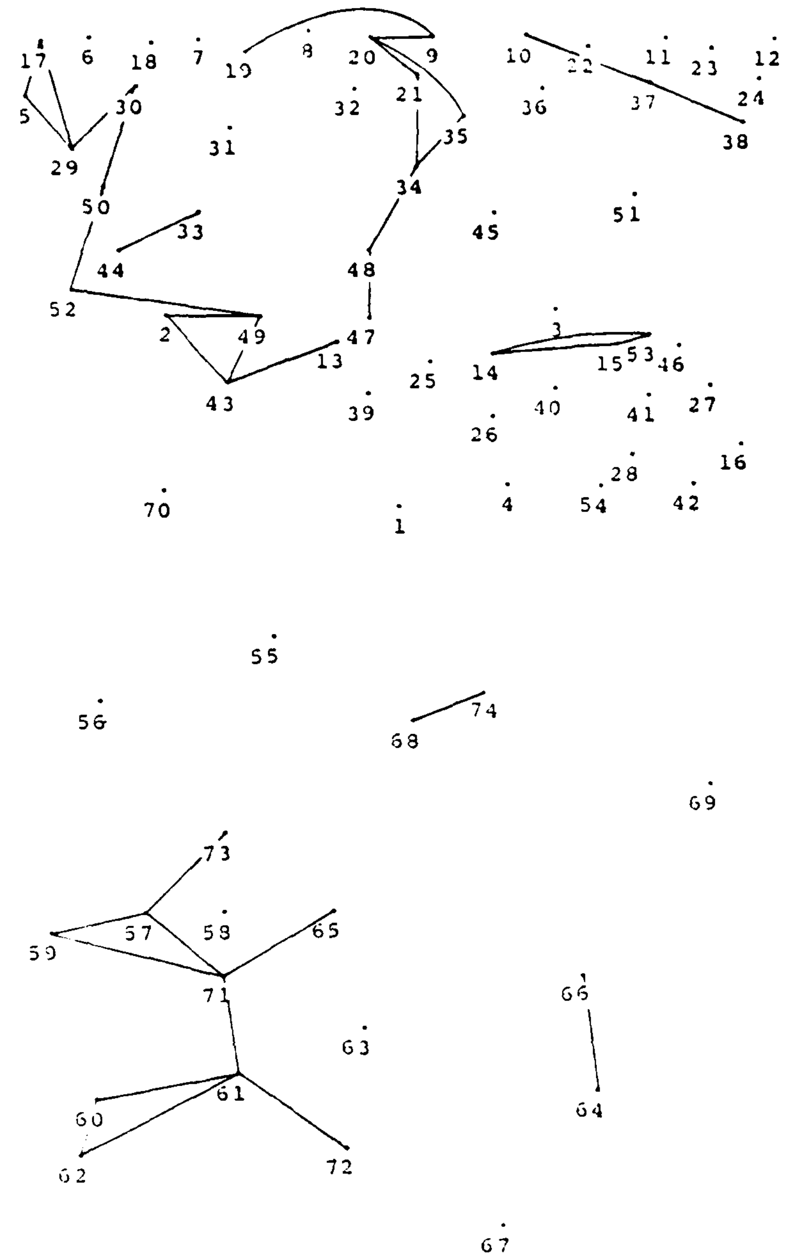

Figure 15. Connectivity at 40 GHz for the first data set.

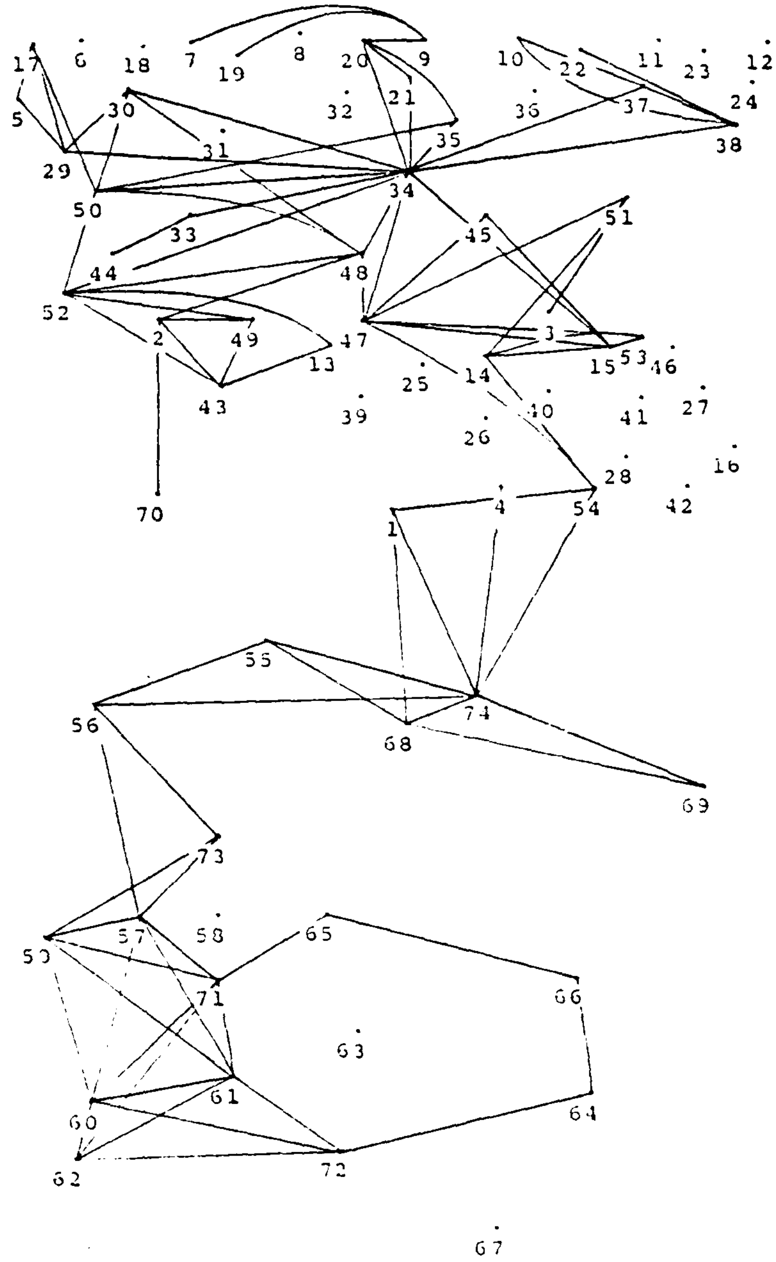

Figure 16. Connectivity at 20 GHz for the first data set.

such as 54 and 56 would cause the system to become disjointed. From Figure 16, it is obvious that a greater reduction in center frequency is still needed. Connectivity of the MAB's units in the SHF band is limited by the poor tree penetration quality and by the requirement to have short links. Units with antennas below the forest ceiling will never be able to connect at frequencies above about 10 GHz. Further analysis was therefore directed not only to finding a good frequency for connectivity but also to finding one with good tree penetration qualities.

C. UHF AND VHF CONNECTIVITY

At frequencies below SHF, Figures 6a, b, and c, and 7 cannot be used to determine path loss. At these lower frequencies the path loss is more accurately approximated by Bullington's equation as shown in Figures 3 and 4. The attenuation due to foliage penetration at VHF and UHF can be determined by Nathanson's equation. Therefore the link loss equation is

$$(\text{Attenuation})_{dB} = \left[\frac{d^2}{h_1 h_2}\right]^2_{dB} + 0.25\ f^{3/4}$$

Figure 17 displays the five nearest neighbors at a center frequency of 1.5 GHz that have a total link loss of less than or equal to 141 dB. The five nearest neighbors concept was

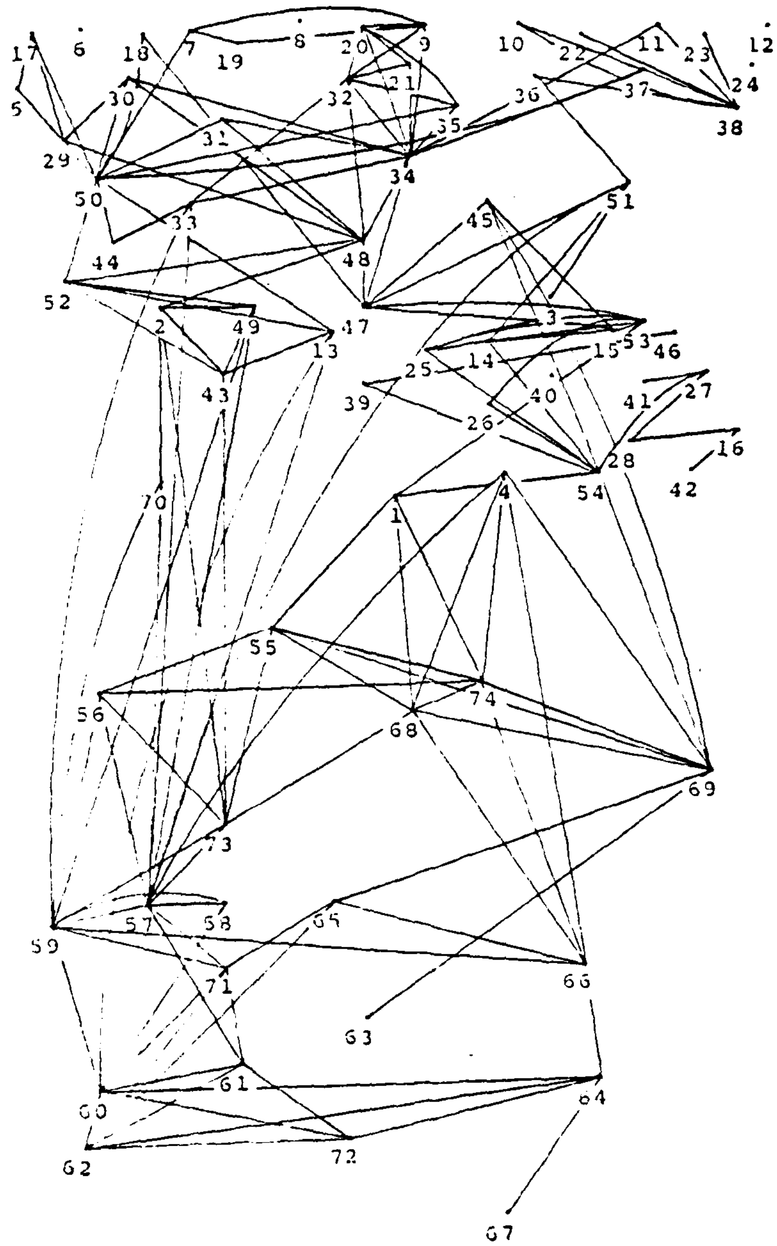

Figure 17. Connectivity for the five nearest neighbors at 1.5 GHz for the first data set.

developed because some nodes see over 20 other nodes. The five nearest neighbors concept functions such that a node displays the five nearest of all the links that it has. Nearest is determined as a function of the x and y coordinates only, and does not take into account changes in elevation. Figure 17 has only five nodes that do not have a single connection with another node, and all of these five have a mobility factor of zero. To connect these nodes, a lower frequency with a better tree penetration quality is needed.

In order to provide a high frequency with ample bandwidth for multi-channel operations, and a low frequency for tree penetration, a frequency pair was analyzed. The high frequency was 1.5 GHz and the low frequency was either 150 MHz or 300 MHz. These three frequencies were used throughout the remainder of the report. The five nearest neighbors concept was still used without regard to whether the link was being carried on the high or low frequency. One of the problems with this concept is that, as the number of low-frequency links increased, there was a decrease in the number of high-frequency links that fell within the five nearest neighbors rule. Though the use of lower-frequency links produced more of a direct path through the network, they were not beneficial to all nodes. Some nodes had high-frequency links capable of carrying multiple channels replaced by narrow-band, short links, capable of carrying only a few channels. This is evident when one compares Figures 17 and 18. Figure 17 is the five nearest high-frequency links, and

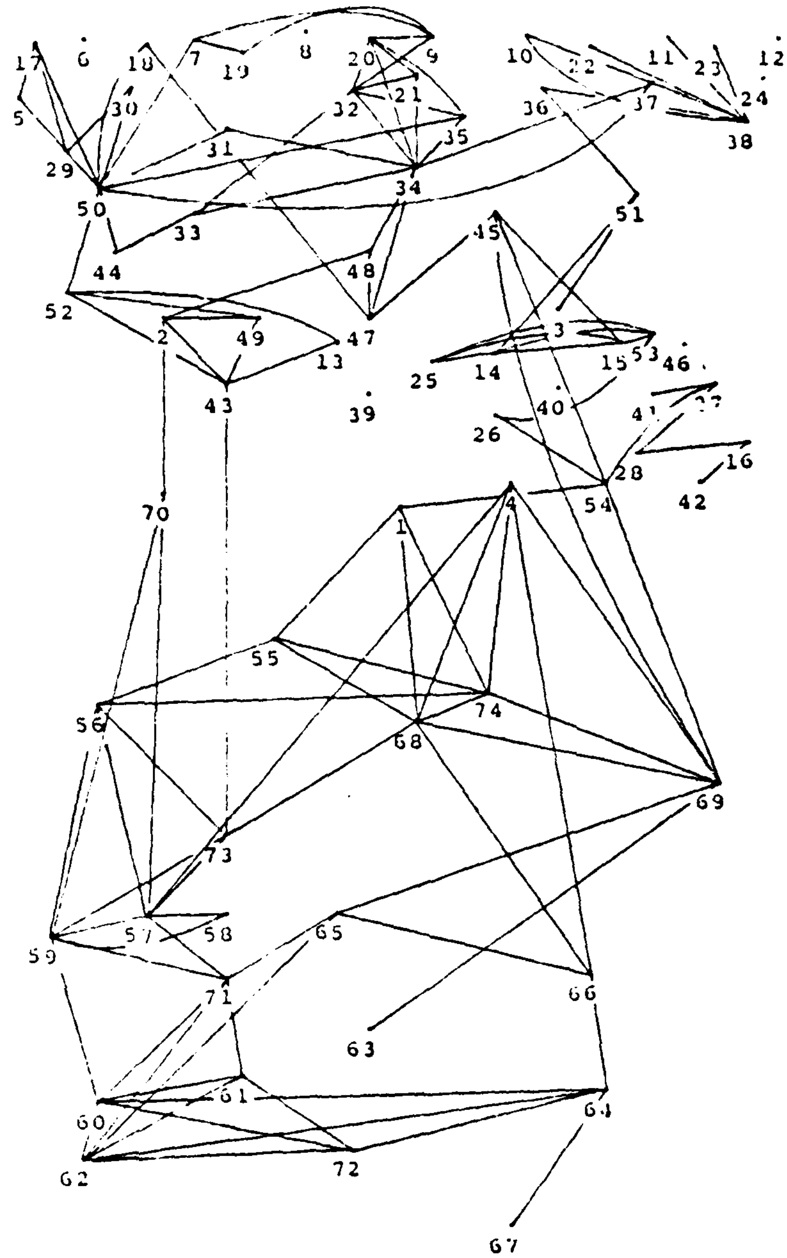

Figure 18. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set.

Figure 18 is the high-frequency links that fit the five nearest neighbors rule when the lower frequency is 300 MHz. There is a 21% reduction in the number of high-frequency links but a 27% increase in the number of total links. The total link connectivity is displayed in Figure 19 where the solid line represents a link that is being carried on the high frequency, and a solid line with a tick mark on it represents a link that is being carried on the low frequency. This is the first connection pattern that includes all the nodes. Figure 19 was generated from Table 6. Table 6 displays the transmit station on the left, the number of links that exist, and the five nearest receiving stations. The second digit under the receiving stations is a zero if the link is being carried on the high frequency and a one if the link is being carried on the low frequency.

If the low frequency is 150 MHz and the high frequency is maintained at 1.5 GHz the connectivity is described in Figure 20. On the average this produces more low-frequency links and reduces the number of high-frequency links that make up the backbone of wideband multi-channel links. The connectivity of the units near the FEBA is increased by the use of 150 MHz, but at the expense of channel capacity throughout the entire network. This decrease in high-frequency links can be seen by comparing Figure 18 for 300 MHz and 1.5 GHz, with Figure 21 for only 150 MHz and 1.5 GHz.

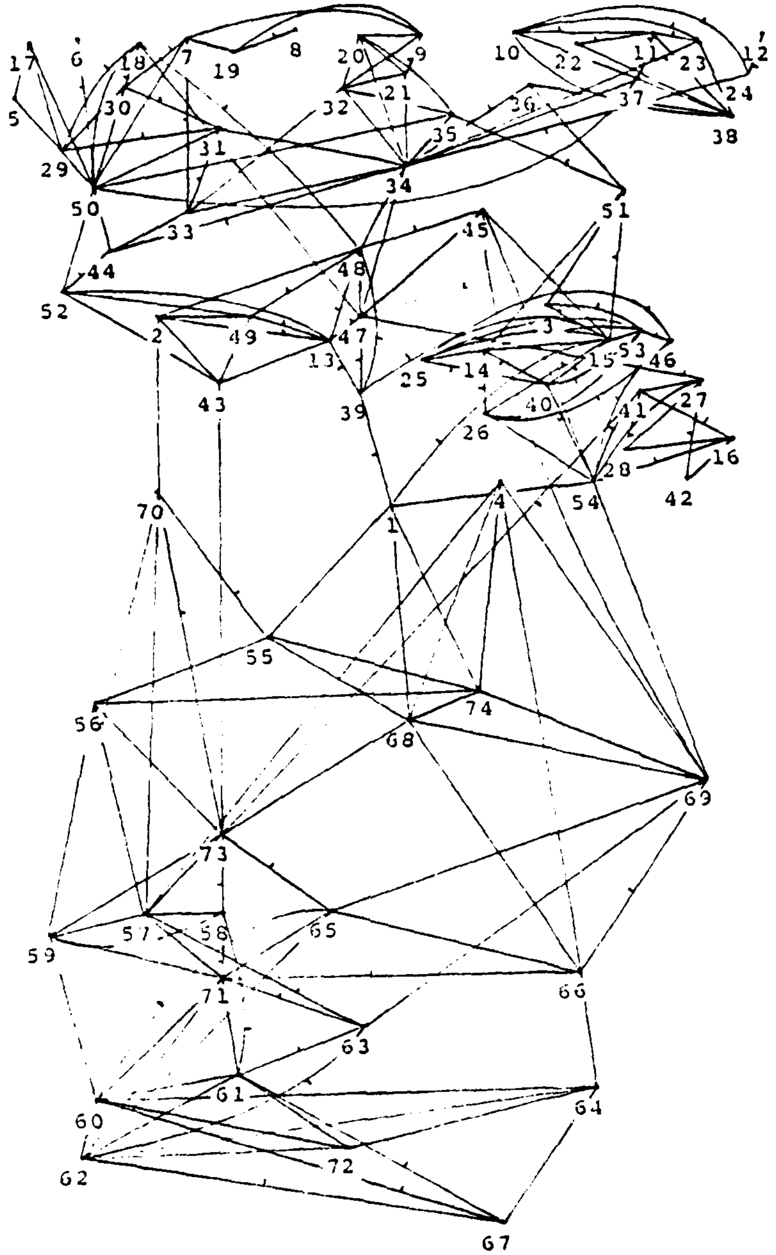

Figure 19. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set. Links with tick marks are carried at the lower frequency.

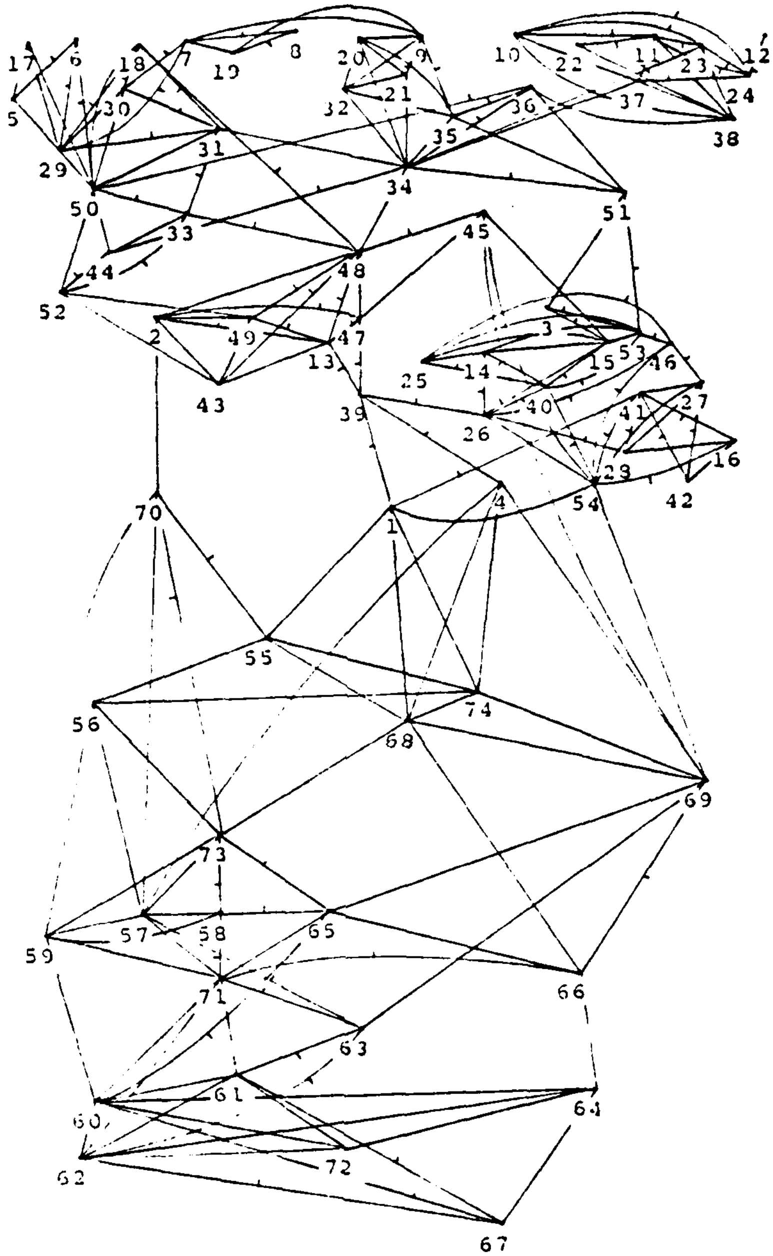

Figure 20. Connectivity for the five nearest neighbors for 150 MHz and 1.5 GHz, for the first data set. Links with tick marks are carried at the lower frequency.

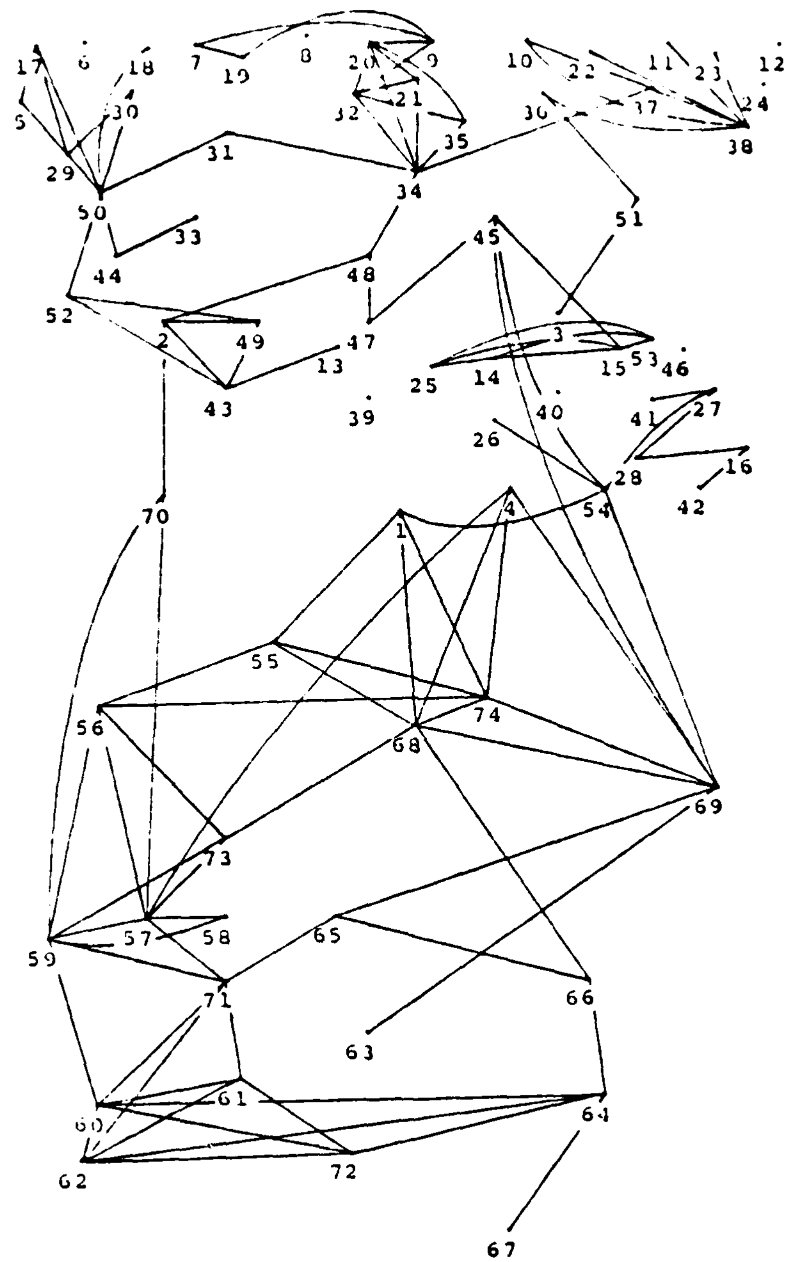

Figure 21. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 150 MHz and 1.5 GHz, for the first data set.

Both of these figures display the high-frequency links that meet the five nearest neighbors rule. By using 150 MHz as the low frequency vice 300 MHz, a 10% reduction in the number of high-frequency links is created.

D. CONNECTIVITY WITH UNIT MOVEMENT

In order to check the MAB's connectivity under different terrain conditions, all units were moved back off the FEBA into the next adjoining grid squares. Figure 22 displays the connectivity for a low frequency of 300 MHz and a high frequency of 1.5 GHz, with unit positions as described in Table 4 and Figure 12. Figure 23 also displays the five nearest neighbors but with a low frequency of 150 MHz. Both figures show evidence of the connectivity problem caused by the 6 km ridge that runs along grid line 59000, just forward of node 59. The connectivity problem caused by ridges and ravines will not be overcome solely by using packet radios. Care must be taken when assigning unit locations so that a repeater or unit is located with connectivity to both sides of the ridge.

The MAB units were moved a second time back into the next adjoining grid squares. The unit locations are described in Table 5 and Figure 13. The connectivity problem encountered by the ridge running along grid line 59000 has been eliminated by positioning repeater number 73 on top of the ridge. Figure 24 displays the five nearest neighbors when only the high frequency of 1.5 GHz is used. Figure 25 shows the

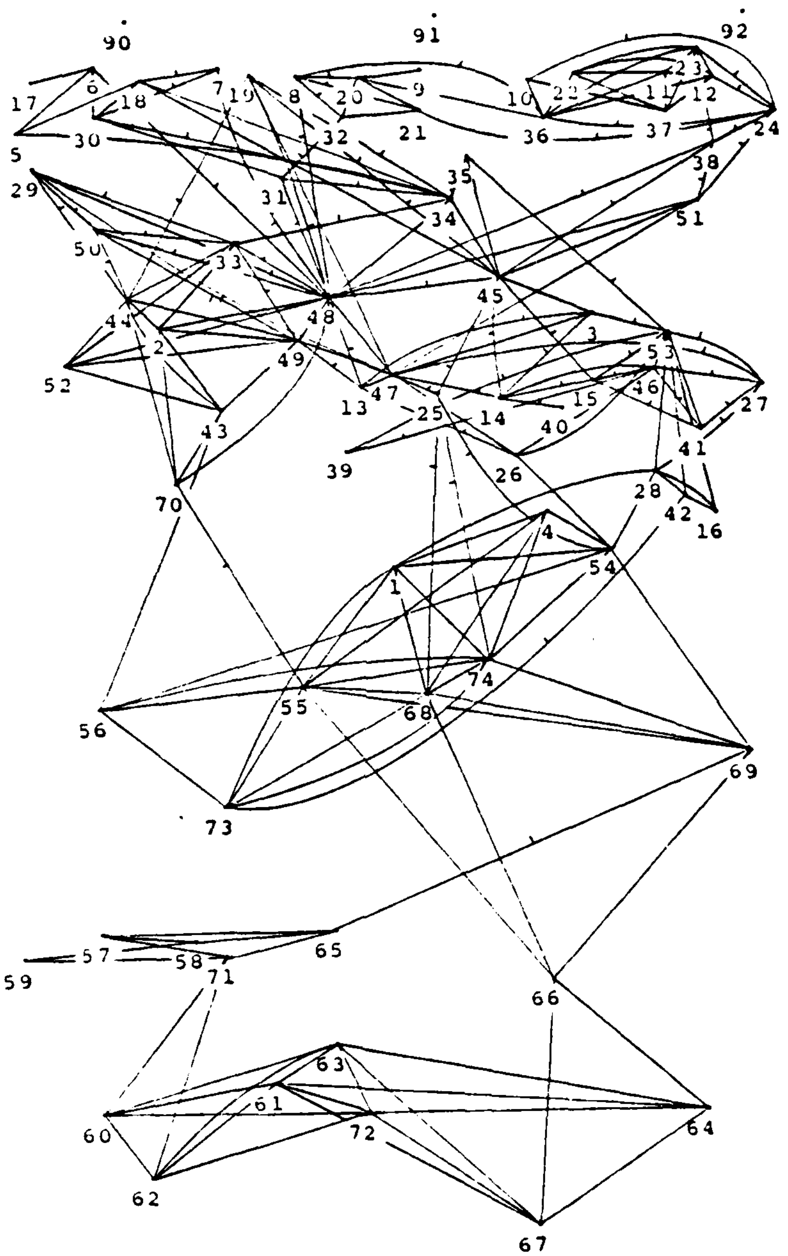

Figure 22. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the second data set. Links with tick marks are carried at the lower frequency.

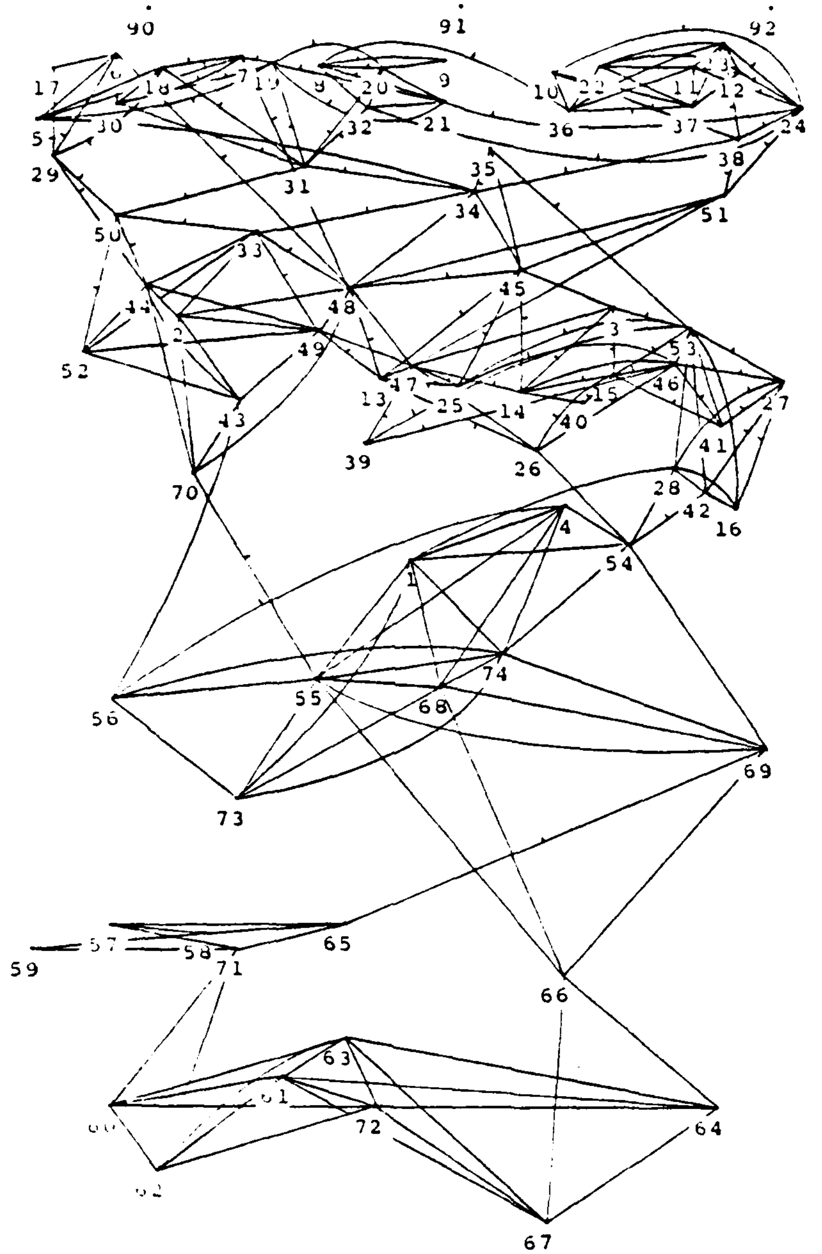

Figure 23. Connectivity for the five nearest neighbors for 150 MHz and 1.5 GHz, for the second data set. Links with tick marks are carried at the lower frequency.

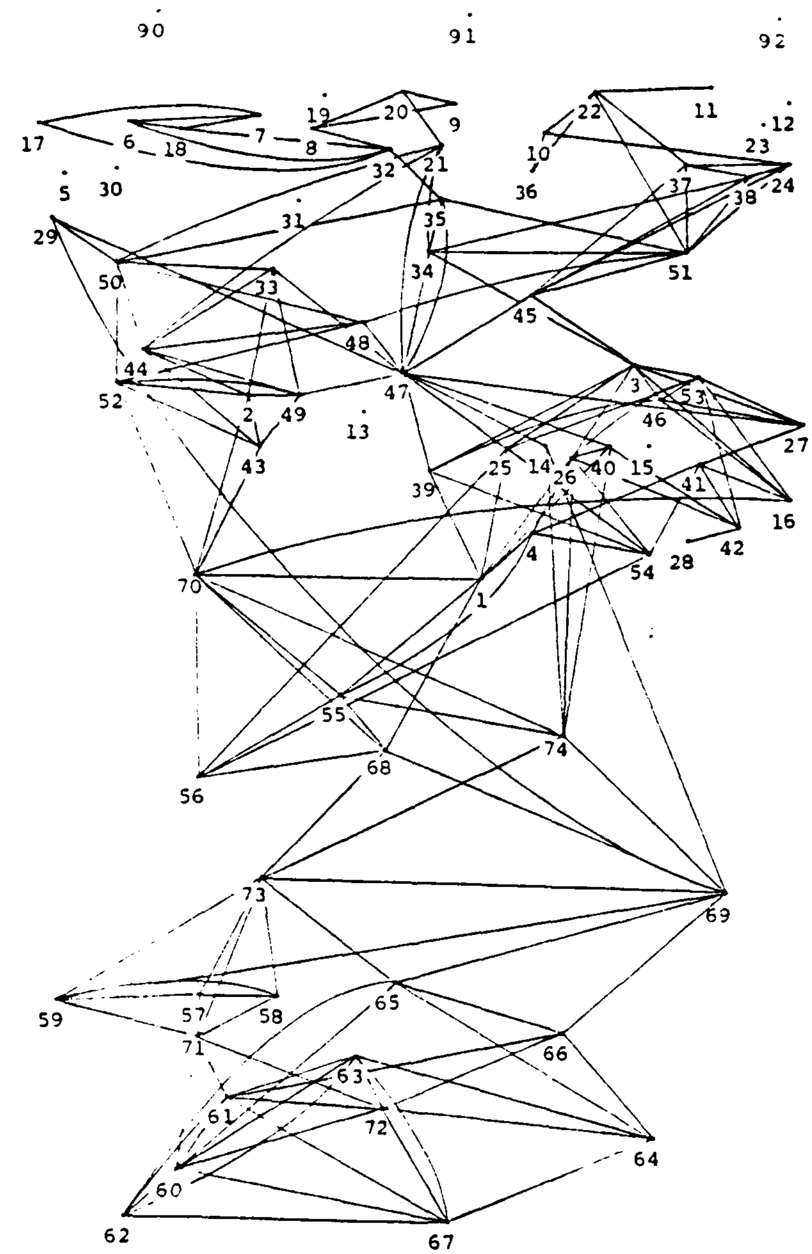

Figure 24. Connectivity for the five nearest neighbors at 1.5 GHz, for the third data set.

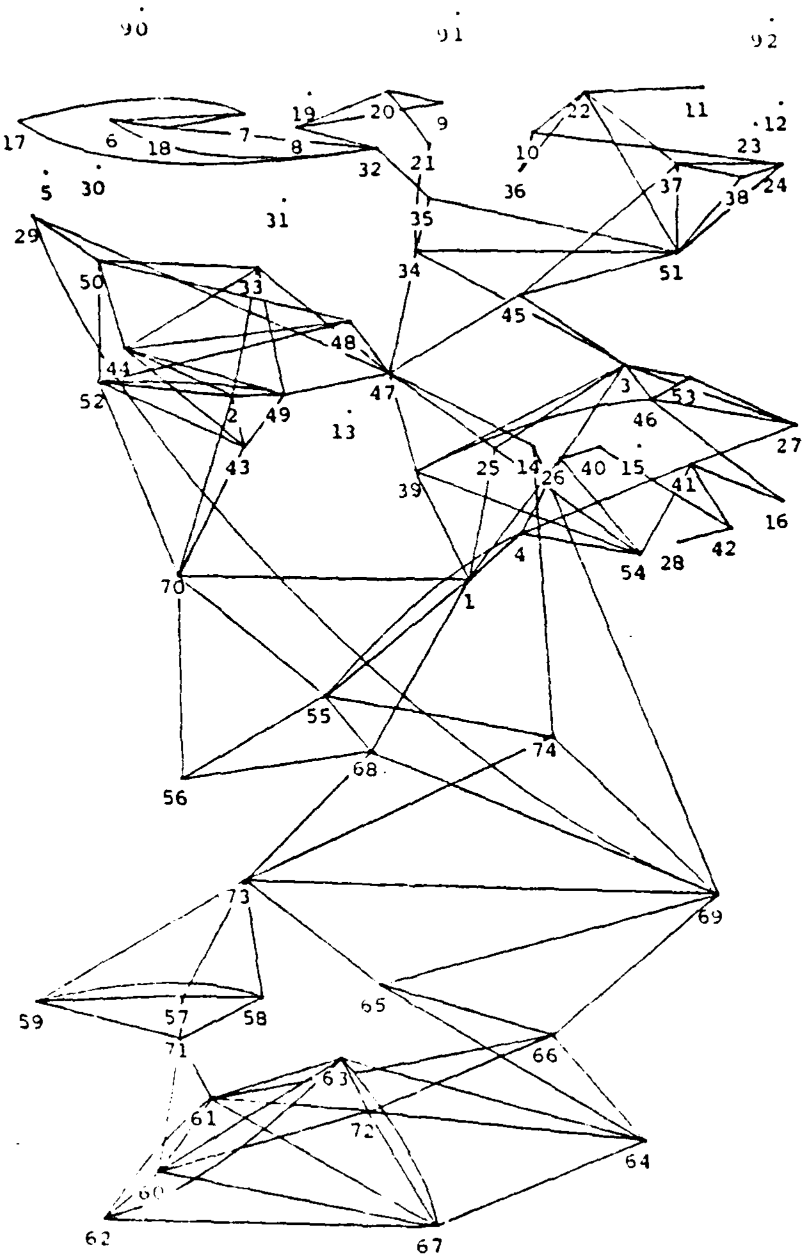

Figure 25. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 300 MHz and 1.5 GHz, for the third data set.

connectivity by the high-frequency links when the five nearest neighbors rule is employed with a low frequency of 300 MHz and a high frequency of 1.5 GHz. The total connectivity for these two frequencies is displayed in Figure 26.

These figures show good connectivity at the high frequency, which is the backbone of the high-volume, multi-channel system. They also provide ample routing capability for all nodes, even the units located near the FEBA with mobility factors of zero.

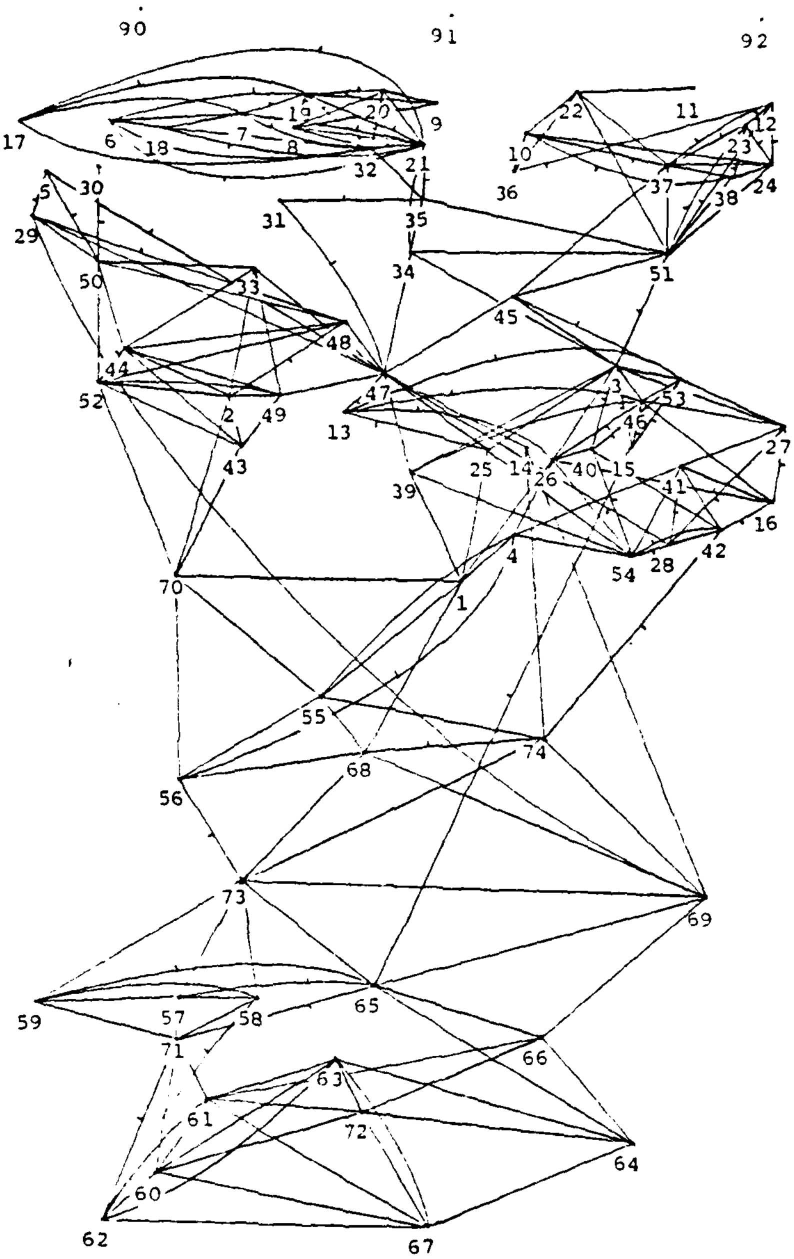

Figure 26. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the third data set. Links with tick marks are carried at the lower frequency.

Table 6. The five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set.

AT	NO	NEIGHBORS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0
2	4	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0
4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	7	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
10	5	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
11	7	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
15	15	0	0	21	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	3	0	0	0	0	0	0	1	21	0	0	0	0	0	0	0	0	0	0
20	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
22	2	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
23	4	0	0	0	0	0	0	0	0	0	31	11	0	0	0	0	0	0	0
24	5	0	0	0	0	0	0	0	0	0	1	0	11	0	0	0	0	0	0
25	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0
26	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	1	31	0	0	0
27	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
29	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30	7	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	11
31	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	11	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
33	[illegible]	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0
34	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	5	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
38	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	11	51	0	0	0	0	0	0	0	0	0	0	0	11	0	51	0	0	0
40	6	0	0	0	0	0	0	0	0	0	0	0	0	0	11	21	0	0	0
41	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0
42	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
43	7	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
44	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
46	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	13	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
48	22	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
49	[illegible]	0	2	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
50	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	[illegible]	0	0	1	0	0	0	0	0	0	0	0	0	0	5	41	0	0	0
52	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	19	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0
55	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[illegible]

		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5	10	0	0	0	0	0	0	0	0	0	0	21	0	0	51	0	0	0
8	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	7	40	10	21	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
10	5	0	0	0	0	11	41	0	0	0	0	0	0	0	0	0	0	0	0
11	7	0	0	0	21	11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
13	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	[illegible]	0	0	0	0	0	0	20	[illegible]	0	0	0	0	0	0	0	0	0	0
15	15	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0
16	4	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0
17	3	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0
18	3	0	0	0	0	0	0	0	0	0	0	21	11	0	0	0	0	0	0
19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	5	0	0	20	0	0	0	0	0	0	0	0	0	0	[illegible]	0	[illegible]	40	0
21	4	0	20	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	40	0	0
22	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0
24	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0
25	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	7	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0
28	[illegible]	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0
29	[illegible]	0	0	0	0	0	0	0	0	0	0	0	[illegible]	41	0	0	0	0	0
30	7	0	0	0	0	0	0	0	0	0	0	[illegible]	0	41	0	0	0	0	0
31	5	0	0	0	0	0	0	0	0	0	0	31	11	0	0	21	50	0	0
32	11	0	20	10	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0
33	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0	[illegible]	0	0
34	[illegible]	0	0	40	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0	0	10	0
35	5	0	30	0	0	0	0	0	0	0	0	0	0	0	20	0	10	0	0
36	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0
37	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0
38	[illegible]	0	0	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
39	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	[illegible]	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0
41	[illegible]	0	0	0	0	0	0	0	0	[illegible]	21	0	0	0	0	0	0	0	0
42	2	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0
43	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	41	0	0
45	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	[illegible]	0	0	0	0	0	0	41	21	0	0	0	0	0	0	0	0	0	0
47	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0
48	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
49	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	[illegible]	0	0	0	0	0	0	0	0	0	0	11	[illegible]	[illegible]	0	0	0	0	0
51	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	[illegible]
52	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	[illegible]	0	0	0	0	0	0	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0
55	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

X[illegible]

		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1	15	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
2	[illegible]	0	0	0	0	0	0	20	0	0	0	0	40	17	0	0	0	0	0
3	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	21	0
4	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0
7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	3	20	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	7	31	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1[illegible]	0	0	21	0	0	0	40	0	0	0	11	51	21	0	0	0	0	0
14	[illegible]	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	5[illegible]	0
15	15	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	10	0
16	4	0	0	0	0	21	10	0	0	0	0	0	0	0	0	0	0	0	41
17	3	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0
18	[illegible]	0	0	0	0	0	0	0	0	0	0	5[illegible]	41	0	[illegible]	0	0	0	0
19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	2	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	4	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	5	0	0	0	21	0	0	0	0	0	51	0	0	0	0	0	0	4[illegible]	0
26	6	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	5[illegible]	20
27	7	0	0	0	0	10	31	0	0	0	0	51	0	0	0	0	0	0	4[illegible]
28	3	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0
29	8	0	0	0	0	0	0	0	0	0	0	0	0	0	1[illegible]	0	0	0	0
30	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	6	0	0	0	0	0	0	0	0	0	0	0	0	0	4[illegible]	0	0	0	0
32	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	8	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
34	29	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0
35	8	0	0	0	0	0	0	0	0	0	0	0	0	0	50	41	0	0	0
36	[illegible]	0	30	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0
37	5	0	20	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0
38	[illegible]	1[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	11	0	0	0	0	0	0	0	0	0	0	21	41	0	0	0	0	0	0
40	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	51
41	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
42	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	7	0	0	0	0	0	0	0	0	0	0	0	0	1[illegible]	0	0	4[illegible]	0	0
44	4	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	11	0	0
45	5	0	0	0	0	0	0	0	0	0	0	2[illegible]	11	0	0	0	0	0	40
46	8	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	11	31
47	16	0	0	31	0	0	0	0	0	40	0	0	20	0	0	0	0	0	0
48	22	0	0	0	0	0	0	0	0	41	0	1[illegible]	0	31	0	0	0	0	0
49	6	0	0	0	0	0	0	3[illegible]	0	0	0	0	41	0	0	0	5[illegible]	0	0
50	26	0	0	0	0	0	0	0	2[illegible]	0	0	0	0	0	0	0	4[illegible]	0	0
51	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	17	0	0	0	0	0	0	4[illegible]	1[illegible]	0	0	0	0	[illegible]	[illegible]	0	0	0	0
53	19	0	0	0	41	0	0	0	0	0	11	0	0	0	0	0	0	0	0
54	29	0	0	0	41	21	0	0	0	0	0	0	0	0	0	0	0	0	0
55	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

XT NO. RECEIVERS

		55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
1	15	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0
3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	[illegible]	0	0	40	0	0	0	0	0	0	0	0	50	0	20	30	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0
46	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	11	0	20	0	0	0	0	0	0	0	0	0	0	0	13	0	51	0	0
56	8	10	0	30	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0

[illegible]

		7[illegible]	7[illegible]
1	13	0	4
2	[illegible]	0	[illegible]
3	3	0	0
4	3	0	10
5	2	0	0
6	1	0	0
7	5	0	0
8	1	0	0
9	7	0	0
10	5	0	0
11	7	0	0
12	1	0	0
13	10	0	0
14	9	0	0
15	15	0	0
16	4	0	[illegible]
17	3	0	0
18	5	0	0
19	3	0	0
20	5	0	0
21	4	0	0
22	2	0	0
23	4	0	0
24	3	0	0
25	6	0	0
26	6	0	0
27	7	0	0
28	3	0	0
29	6	0	0
30	7	0	0
31	5	0	0
32	11	0	0
33	6	0	0
34	24	0	0
35	5	0	0
36	3	0	0
37	5	0	0
38	3	0	0
39	11	0	0
40	6	0	0
41	5	51	0
42	2	0	0
43	7	60	0
44	4	0	0
45	5	0	0
46	9	0	0
47	13	0	0
48	22	0	0
49	3	0	0
50	26	0	0
51	4	0	0
52	17	0	0
53	19	0	0
54	29	0	0
55	11	0	30
56	8	20	40

KT [illegible] RECEIVERS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
57	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	1[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	9	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	1[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	5	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	12	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[illegible]

		19	[illegible]	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	31	[illegible]	[illegible]	[illegible]	35	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
71	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

		[illegible]	[illegible]	[illegible]	[illegible]	41	42	43	44	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ST (SEQUENCE

		55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
57	27	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	30	0
58	7	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	21	0
59	0	0	0	10	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	16	0	0	0	0	10	0	20	10	0	0	0	0	0	0	0	0	0	40
61	9	0	0	0	0	0	10	0	50	21	0	0	0	0	0	0	0	40	30
62	0	0	0	0	0	0	10	20	0	51	0	0	0	0	0	0	0	40	30
63	0	0	0	31	0	0	0	11	41	0	0	0	0	0	0	50	0	21	0
64	5	0	0	0	0	0	40	0	50	0	0	0	10	20	0	0	0	0	30
65	0	0	0	0	0	0	41	0	0	0	0	0	20	0	0	0	0	0	0
66	15	0	0	0	0	0	0	0	0	0	10	20	0	0	50	31	0	41	0
67	4	0	0	0	0	0	41	21	31	0	11	0	0	0	0	0	0	0	0
68	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0
69	10	0	0	0	0	0	0	0	0	0	0	40	31	0	20	0	0	0	0
70	5	11	0	40	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
71	11	0	0	20	11	0	0	50	0	41	0	20	0	0	0	0	0	0	0
72	0	0	0	0	0	0	30	10	20	0	40	0	0	0	0	0	0	0	0
73	21	0	50	20	11	40	0	0	0	0	0	31	0	0	0	0	0	0	0
74	12	20	0	0	0	0	0	0	0	0	0	0	0	0	10	40	0	0	0

[illegible]

		73	74
57	27	[illegible]	[illegible]
58	7	31	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
60	16	[illegible]	[illegible]
61	9	[illegible]	0
62	6	[illegible]	0
63	5	[illegible]	[illegible]
64	5	[illegible]	[illegible]
65	7	41	[illegible]
66	15	[illegible]	[illegible]
67	4	[illegible]	[illegible]
[illegible]	[illegible]	36	10
[illegible]	14	[illegible]	1[illegible]
70	5	31	[illegible]
71	11	[illegible]	[illegible]
72	4	[illegible]	[illegible]
73	11	[illegible]	[illegible]
74	12	[illegible]	0

VI. ENEMY INTERCEPT

Three enemy listening posts (LP) were established in order to determine which units were capable of transmitting across the FEBA. The listening posts were numbered 90, 91 and 92, and were located at 40050 11650, 40050 15500, and 40050 19500. For each LP, an analysis was done to determine if an RF link existed to any one of the 74 nodes. If a link existed, then the SNR at the receiver input for an antenna gain of 5.83 dB was given. This SNR was given for both the low and high frequencies that the transmitter might be using. The distance between the LP and node was also given along with the amount of forests penetrated.

Table 7 shows all the links that exist for a low frequency of 150 MHz and a high frequency of 1.5 GHz. The units are located at the first set of data points as described in Figure 11. Figure 27 displays all the nodes that produce an SNR of greater than -30 dB at any one of the listening posts. The nodes with the large dots are the ones that can be intercepted. If the high frequency only is displayed as in Figure 28, there is a noticeable reduction in the number of nodes that produce an SNR > - 30 dB at the FEBA. Therefore the high frequency is again recommended because of its bandwidth and low probability of intercept.

If the units are moved back off the FEBA one grid square to locations as in Figure 12, the stations that can be

Table 7. The nodes that can be intercepted for 150 MHz and 1.5 GHz, for the first data set. The distance and amount of forest between nodes is also displayed.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	3	[illegible]	[illegible]	[illegible]	[illegible]
90	13	[illegible]	[illegible]	[illegible]	[illegible]
90	15	[illegible]	[illegible]	[illegible]	[illegible]
90	15	[illegible]	[illegible]	[illegible]	[illegible]
90	27	[illegible]	[illegible]	[illegible]	[illegible]
90	29	[illegible]	[illegible]	[illegible]	[illegible]
90	30	[illegible]	[illegible]	[illegible]	[illegible]
90	31	[illegible]	[illegible]	[illegible]	[illegible]
90	34	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	47	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	54	[illegible]	[illegible]	[illegible]	[illegible]
90	57	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	65	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
91	7	[illegible]	[illegible]	[illegible]	[illegible]
91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
91	17	[illegible]	[illegible]	[illegible]	[illegible]
91	20	[illegible]	[illegible]	[illegible]	[illegible]
91	21	[illegible]	[illegible]	[illegible]	[illegible]
91	32	[illegible]	[illegible]	[illegible]	[illegible]
91	34	[illegible]	[illegible]	[illegible]	[illegible]
91	35	[illegible]	[illegible]	[illegible]	[illegible]
91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	10	[illegible]	[illegible]	[illegible]	[illegible]
92	11	[illegible]	[illegible]	[illegible]	[illegible]
92	12	[illegible]	[illegible]	[illegible]	[illegible]
92	13	[illegible]	[illegible]	[illegible]	[illegible]
92	14	[illegible]	[illegible]	[illegible]	[illegible]
92	15	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	23	[illegible]	[illegible]	[illegible]	[illegible]
92	24	[illegible]	[illegible]	[illegible]	[illegible]
92	34	[illegible]	[illegible]	[illegible]	[illegible]
92	35	[illegible]	[illegible]	[illegible]	[illegible]
92	37	47.2	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	44	[illegible]	[illegible]	[illegible]	[illegible]
92	47	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	50	[illegible]	[illegible]	[illegible]	[illegible]
92	51	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	53	[illegible]	[illegible]	[illegible]	[illegible]
92	57	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 27. The nodes with the large dots can be intercepted with a SNR greater than -30 dB if they are transmitting at 150 MHz, first data set.

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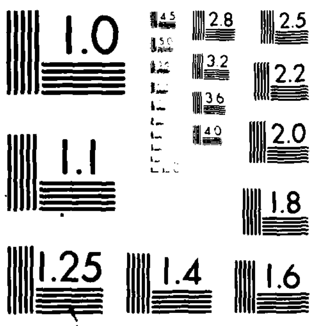

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

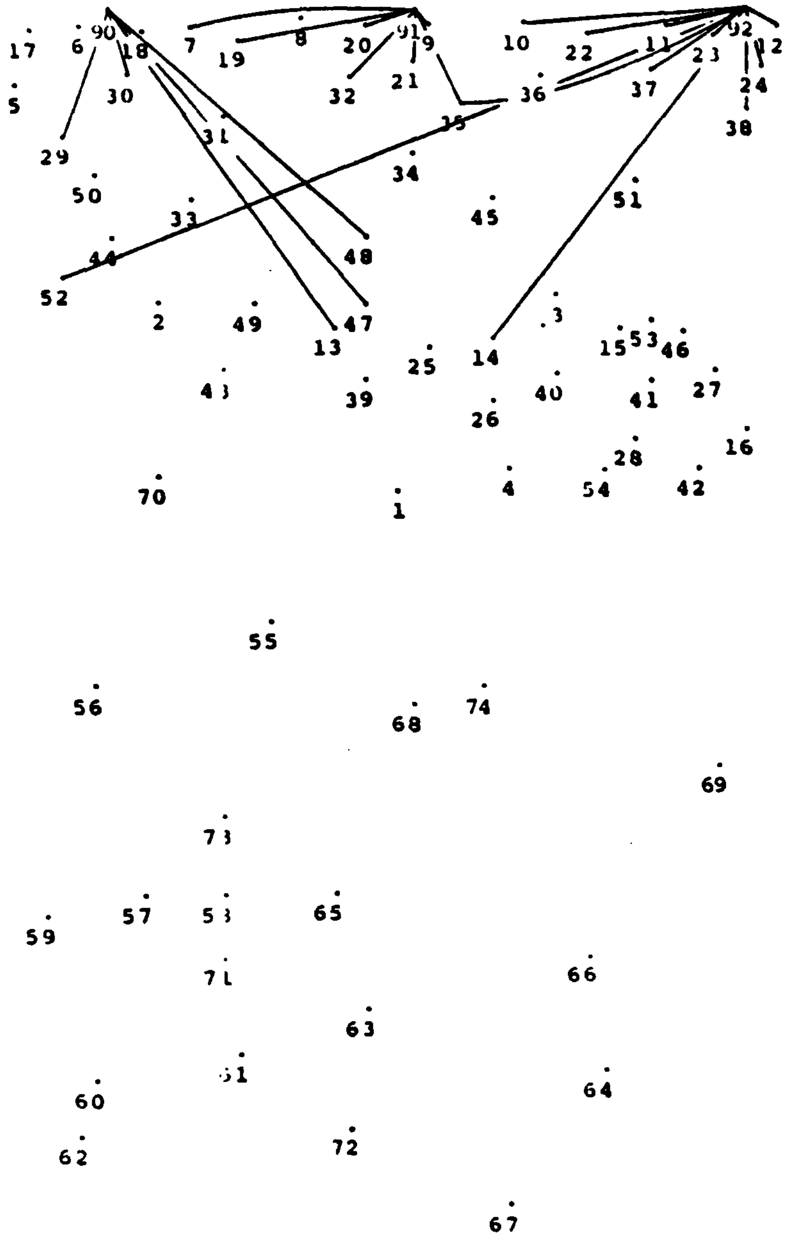

Figure 28. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, first data set.

intercepted at the low frequency appear in Figure 29 and the high frequency in Figure 30. Finally, if the units are again moved as in Figure 13, the units that can be intercepted at the low frequency appear in Figure 31 and the high frequency in Figure 32. These figures show that the probability of intercept decreases with increasing distance and frequency, as was expected. It is evident that, in order to decrease the amount of traffic intercepted, the low, tree-penetration frequencies should be used sparingly.

Figure 29. The nodes with the large dots can be intercepted with a SNR greater than -30 dB if they are transmitting at 150 MHz, second data set.

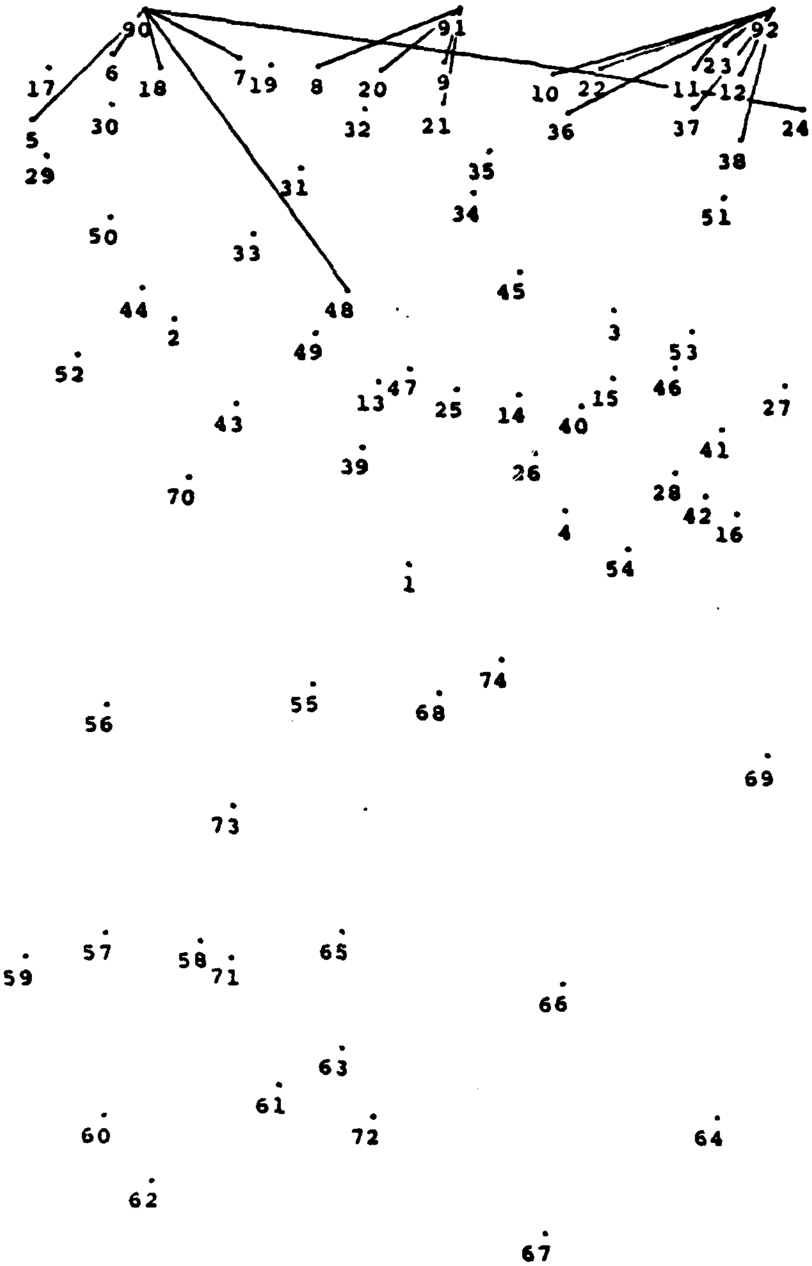

Figure 30. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, second data set.

Figure 31. The nodes with the large dots can be intercepted with a SNR greater than -30 dB if they are transmitting at 150 MHz, third data set.

Figure 32. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, third data set.

VII. CONCLUSIONS AND RECOMMENDATIONS

From the data presented in this report, it can be concluded that connectivity to support a practical packet radio system can be provided for terrain typical of western Europe. The system should have the capability of transmitting on at least two frequencies in the VHF and UHF bands. One of these frequencies should be in the high VHF range and would be needed as the tree-penetration frequency. The other frequency could be near 1.5 Hz and would be used as the wide-band, multi-channel frequency.

The algorithm used for selecting the frequency in the packet radio should make maximum use of the high frequency. The low frequency need only be used where the high frequency fails to connect with another node. Relying on the high frequency will not only increase the total system's channel capacity, but will also decrease the probability of being intercepted.

Figure 33 shows the connectivity under these constraints. The system is based on the five nearest neighbors rule for the third set of data points and a high frequency of 1.5 GHz. Then only the nodes without connectivity were permitted to use the lower frequency of 300 MHz. This network has 95% of the links being carried on the high frequency and only 35% of the nodes with the capability of being intercepted, as shown in Figure 34.

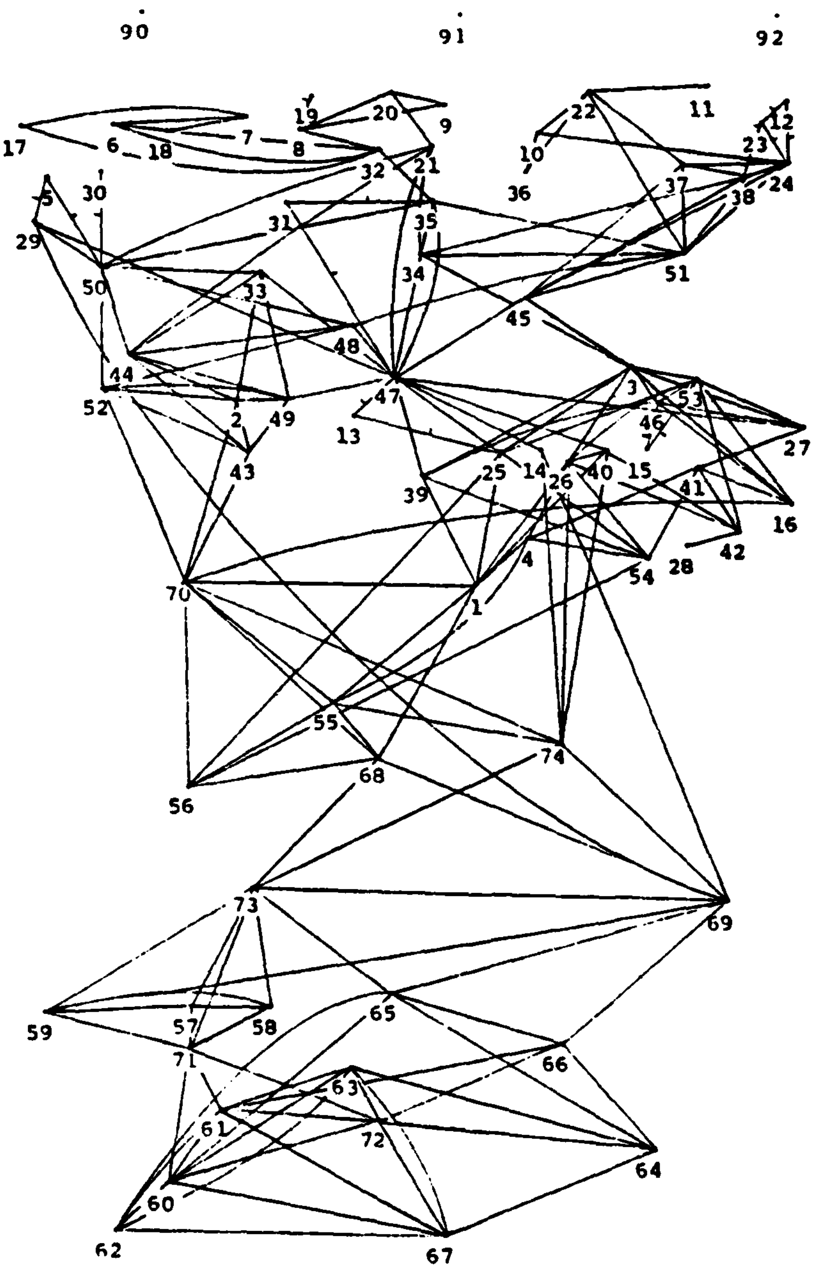

Figure 33. Connectivity for the five nearest neighbors at 1.5 GHz with selected nodes using 300 MHz, third data set. Links with tick marks are carried at the lower frequency.

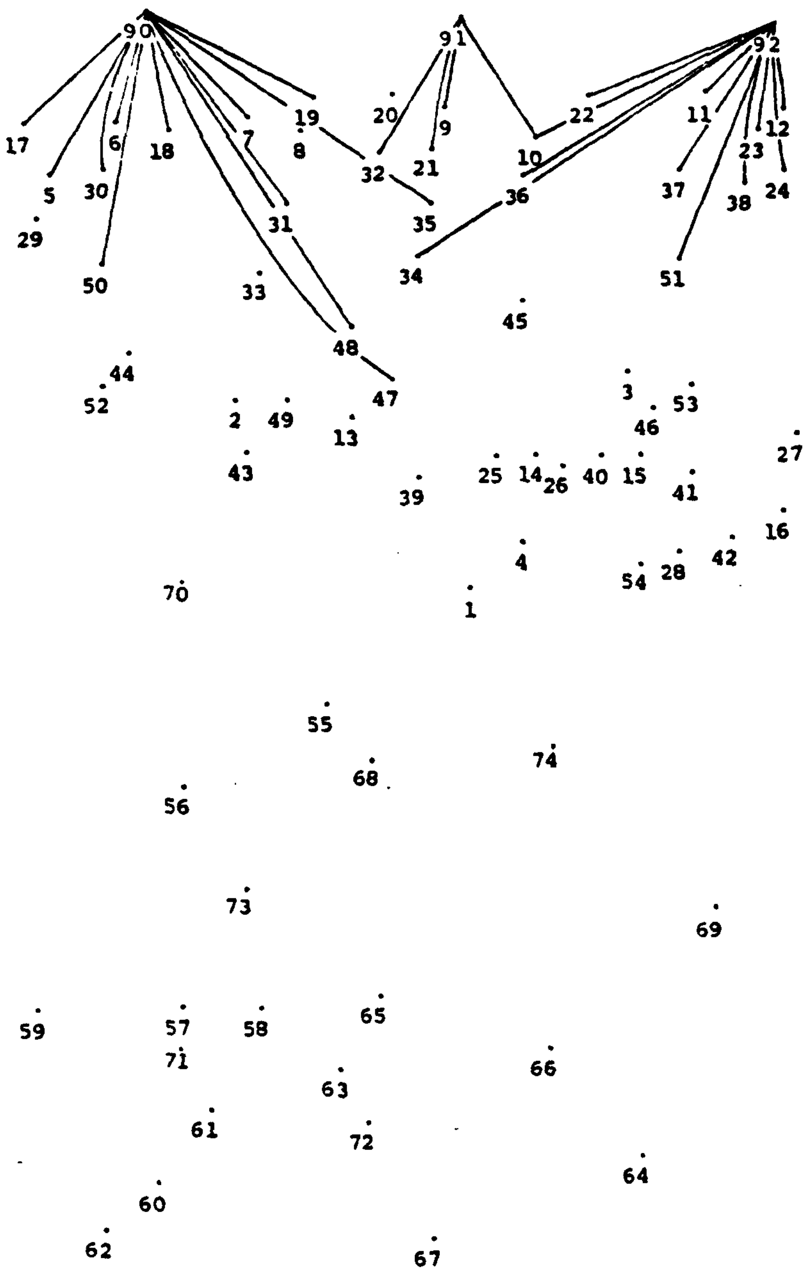

Figure 34. Links that can be intercepted with a SNR greater than -30 dB for 300 MHz and 1.5 GHz, third data set.

APPENDIX A

```
//TGK1002 JOB (1420,0238,DC91),'TRY ONE',TIME=10
// EXEC SIM25CLG,REGION.GO=250K
//SIM.SYSIN DD *

PREAMBLE

''GLOBAL DEFINITIONS FOR TERRAIN AND FORESTS
DEFINE NGRIDX,NGRIDY,NHILLS,NCVELS AS INTEGER VARIABLES
DEFINE DUM.I AS A 1-DIMENSIONAL INTEGER ARRAY
DEFINE KCREP , KHREP AS 1-DIMENSIONAL INTEGER ARRAYS
DEFINE LIST.H, LIST.C AS 3-DIMENSIONAL INTEGER ARRAYS
DEFINE GSIZE,X.LO.BDRY,Y.LO.BDRY AS REAL VARIABLES
DEFINE XC.H,YC.H,PEAK.H,HT.H,PXX.H,PYY.H,PXY.H,CRIT.H,XC.E,YC.E,HT.E,
    PXX.E,PYY.E,PXY.E  AS 1-DIMENSIONAL REAL ARRAYS
'' GLOBAL DEFINITIONS FOR LOS AND ASSOCIATED ROUTINES -- ALL END WITH .LS
DEFINE NGRSQ.LS,LATOB.LS,LBTOA.LS,LAGA.LS,LAGB.LS,LAG.LS,ISGX.LS,ISGY.LS,
    IX.LS,IY.LS,NELS.LS,NCT.LS                          AS INTEGER VARIABLES
DEFINE IGX.LS,IGY.LS,IEL.LS            AS 1-DIMENSIONAL INTEGER ARRAYS
DEFINE XA.LS,XB.LS,XBA.LS,YA.LS,YB.LS,YBA.LS,VISFRA.LS,VISFRB.LS,
    SIZEA.LS,SIZEB.LS,TMICA.LS,TMICB.LS,TMACA.LS,TMACB.LS,ZA.LS,ZB.LS,
    ZBA.LS,XBASQ.LS,YBASQ.LS,XYBA.LS,TWOXBA.LS,TWOYBA.LS,CHTMAX.LS,
    CPK.LS,XINC.LS,YINC.LS,XSTEP.LS,YSTEP.LS,RX.LS,RY.LS,PXX.LS,PYY.LS,PXY.LS,
    AA.LS,BB.LS,CC.LS,ARG.LS,SQ.LS,S1.LS,S2.LS,SS.LS,BASE.LS,GQ.LS,FQ.LS,EQ.LS,
    W.LS,FSQ.LS,POW.LS,PK.LS,HT.LS,HHW.LS,ZW.LS,CVHTW.LS,ZZ.LS,VSUB.LS,XS.LS,
    YS.LS,HTS.LS,ZS.LS,V.LS,VM.LS,HHV.LS,TWOGV.LS,FCNV.LS,DFCNV.LS,
    ELV.LS,CVHTV.LS,HTV.LS,ZV.LS                        AS REAL VARIABLES
DEFINE CS1.LS,CS2.LS AS 1-DIMENSIONAL REAL ARRAYS
DEFINE AX, AY AS 1-DIMENSIONAL REAL ARRAYS
DEFINE NODE.NO AS A 1-DIMENSIONAL INTEGER ARRAY
DEFINE NO.OF.PTS AS INTEGER VARIABLE
DEFINE NO.PER.ROW AS 1-DIMENSIONAL INTEGER ARRAY
DEFINE MATRIX.ORDER AS A 2-DIMENSIONAL INTEGER ARRAY
DEFINE FOREST.PERCENT, WOODS, LINK.LOSS, FREQ.L, FREQ.H, LAMDA.L, LAMDA.H,
    TREE.A.HT, TREE.B.HT AS REAL VARIABLES
DEFINE KTREP, TEMP.NCVELS AS INTEGER VARIABLES
DEFINE LINES.V AS A INTEGER VARIABLE
DEFINE MOBILITY AS 1-DIMENSIONAL INTEGER ARRAY
DEFINE ANT.A.HT,ANT.B.HT AS REAL VARIABLES
END
```

```
MAIN

DEFINE MAXLOS,DISTANCE AS REAL VARIABLES
DEFINE LAND.VISFRB AS REAL VARIABLE
DEFINE I, J, K, II, JJ, SMALLEST, KK,
NODE.J, NODE.K, X, JX, XZ AS INTEGER VARIABLES
DEFINE MATRIX.DISTANCE AS A 2-DIMENSIONAL REAL ARRAY
DEFINE FREE.SPACE.L,FREE.SPACE.H,BULLINGTON.LOSS,MARGIN,LOSS.L,LOSS.H
  AS REAL VARIABLES
LET LINES.V = 80
CALL RES.TERR
LET TEMP.NCVELS = NCVELS
READ SIZEA.LS, SIZEB.LS
READ MAXLOS, NO.OF.PTS
RESERVE AX(*), AY(*), NODE.NO(*), NO.PER.ROW(*),MOBILITY(*) AS NO.OF.PTS
RESERVE MATRIX.DISTANCE(*,*),MATRIX.ORDER(*,*) AS NO.OF.PTS BY NO.OF.PTS
LET FREQ.L = 0.300  ''GHZ OR 300MHZ
LET LAMDA.L = 0.3/FREQ.L
LET FREQ.H = 1.5  ''GHZ
LET LAMDA.H = 0.3/FREQ.H
LET LINK.LOSS = 141   ''DB
LET LAGB.LS = 1
LET LAGA.LS = 1
LET LBTOA.LS = 0
LET LATOB.LS = 1
FOR I = 1 TO NO.OF.PTS, READ AX(I), AY(I), NODE.NO(I),J, MOBILITY(I)
FOR J = 1 TO NO.OF.PTS - 1, DO
    LET MATRIX.DISTANCE(J,J) = MAXLOS*10
    LET MATRIX.DISTANCE(NO.OF.PTS,NO.OF.PTS) = MAXLOS*10
    FOR K = J + 1 TO NO.OF.PTS, DO
        LET NODE.K = NODE.NO(K)
        LET NODE.J = NODE.NO(J)
        LET NCVELS = TEMP.NCVELS
        LET TMICA.LS = 0.
        LET TMICB.LS = 0.
        LET MATRIX.DISTANCE(NODE.K,NODE.J) = MAXLOS*10
        LET MATRIX.DISTANCE(NODE.J,NODE.K) = MAXLOS*10
        LET DISTANCE = SQRT.F((AX(J) - AX(K))**2 + (AY(J) - AY(K))**2)
        CALL ELEV GIVEN AX(J), AY(J) YIELDING TMACA.LS
        CALL ELEV GIVEN AX(K), AY(K) YIELDING TMACB.LS
        CALL TREES GIVEN AX(J), AY(J) YIELDING TREE.A.HT
        CALL TREES GIVEN AX(K), AY(K) YIELDING TREE.B.HT
        IF MOBILITY(J) EQ 1
        LET TMICA.LS = TREE.A.HT
        ALWAYS
        IF MOBILITY(K) EQ 1
        LET TMICB.LS = TREE.B.HT
```

```
                ALWAYS
                LET ANT.A.HT = SIZEA.LS + TMICA.LS
                LET ANT.B.HT = SIZEB.LS + TMICB.LS
                LET XA.LS = AX(J)
                LET YA.LS = AY(J)
                LET XB.LS = AX(K)
                LET YB.LS = AY(K)
                LET NCVELS = 0
                CALL LOS
                IF VISFRB.LS LE 0, CYCLE
                ALWAYS
    LET FREE.SPACE.L = 10*LOG.10.F((4*PI.C*DISTANCE/LAMDA.L)**2)
    LET FREE.SPACE.H = 10*LOG.10.F((4*PI.C*DISTANCE/LAMDA.H)**2)
    LET BULLINGTON.LOSS = 10*LOG.10.F(DISTANCE**4/(ANT.A.HT*ANT.B.HT)**2)
    LET LOSS.L = FREE.SPACE.L
    IF BULLINGTON.LOSS GT LOSS.L,  LET LOSS.L = BULLINGTON.LOSS  ALWAYS
    LET LOSS.H = FREE.SPACE.H
    IF BULLINGTON.LOSS GT LOSS.H,  LET LOSS.H = BULLINGTON.LOSS  ALWAYS
                LET LAND.VISFRB = VISFRB.LS
                LET NCVELS = TEMP.NCVELS
                CALL LOS
                LET DISTANCE = DISTANCE-FRAC.F(DISTANCE)
                LET WOODS = 0
                IF VISFRB.LS LE 0.0, CALL FOREST YIELDING FOREST.PERCENT
                IF FOREST.PERCENT LE 0.0 LET FOREST.PERCENT = 0.01   ALWAYS
                LET  WOODS = FOREST.PERCENT * DISTANCE
                LET DISTANCE = DISTANCE + 0.1
                IF LINK.LOSS LT LOSS.L + WOODS*0.25*FREQ.L**0.75 CYCLE ALWAYS
    LET MARGIN = LINK.LOSS - LOSS.L - WOODS*0.25*FREQ.L**0.75
                ALWAYS
                IF LINK.LOSS GT LOSS.H + WOODS*0.25*FREQ.H**0.75,
    LET MARGIN = LINK.LOSS - LOSS.H - WOODS*0.25*FREQ.H**0.75
                LET DISTANCE = DISTANCE - FRAC.F(DISTANCE)  ALWAYS
                PRINT 4 LINES WITH XA.LS, YA.LS, NODE.NO(J), TMACA.LS, TREE.A.HT,
                ANT.A.HT,XB.LS,YB.LS,NODE.NO(K),TMACB.LS,TREE.B.HT,ANT.B.HT,
                LAND.VISFRB,DISTANCE,WOODS,VISFRB.LS,MARGIN AS FOLLOWS
X = *****|****  NODE = **  ELEV = *****.**  TREE HT = ***.*  ANT HT = ***.*
Y = *****|****  NODE = **  ELEV = *****.**  TREE HT = ***.*  ANT HT = ***.*
%LOS.L = **.**  DISTANCE = *****.**         TREE DEPTH = *****.**
%LOS.T = **.**  MARGIN = ****.** DB
                SKIP 1 OUTPUT LINE
                LET MATRIX.DISTANCE(NODE.K,NODE.J) = DISTANCE
                LET MATRIX.DISTANCE(NODE.J,NODE.K) = DISTANCE
                LET NO.PER.ROW(NODE.J) = NO.PER.ROW(NODE.J) + 1
                LET NO.PER.ROW(NODE.K) = NO.PER.ROW(NODE.K) + 1
          LOOP. ''K''
    LOOP ''J''
    FOR II = 1 TO NO.OF.PTS, DO
```

```
          FOR JJ = 1 TO 5, DO
               LET SMALLEST = 1
               FOR KK = 2 TO NO.OF.PTS, DO
               IF MATRIX.DISTANCE(II,SMALLEST) LE MATRIX.DISTANCE(II,KK), CYCLE
                    ALWAYS
                    LET SMALLEST = KK
               LOOP ''KK''
               IF MATRIX.DISTANCE(II,SMALLEST) EQ MAXLOS*10, CYCLE
               ALWAYS
               LET MATRIX.ORDER(II,SMALLEST) = JJ*10 +
               INT.F(FRAC.F(MATRIX.DISTANCE(II,SMALLEST))*10)
               LET MATRIX.DISTANCE(II,SMALLEST) = MAXLOS*10
          LOOP  ''JJ''
     LOOP  ''II''
     CALL REPORT.PRINT
     CALL LPI
     STOP
     END
```



```
     ROUTINE REPORT.PRINT

     DEFINE IJ, JI AS INTEGER VARIABLES
     BEGIN REPORT PRINTING FOR IJ = 1 TO NO.OF.PTS IN GROUPS OF 25 PER PAGE
     BEGIN HEADING
     PRINT 1 LINE AS FOLLOWS
XT NO  RECEIVERS
     SKIP 1 OUTPUT LINE
     PRINT 1 LINE WITH A GROUP OF IJ FIELDS THUS
       ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
     SKIP 1 OUTPUT LINE
     END '' HEADING
     FOR JI = 1 TO NO.OF.PTS, PRINT 1 LINE WITH JI, NO.PER.ROW(JI),
          AND A GROUP OF MATRIX.ORDER(JI,IJ) FIELDS THUS
** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
     END '' REPORT
     LET LINES.V = 64
     BEGIN REPORT PRINTING FOR IJ = 1 TO NO.OF.PTS IN GROUPS OF 18 PER PAGE
     BEGIN HEADING
     SKIP 4 OUTPUT LINES
```

```
      PRINT 1 LINE AS FOLLOWS
            XT NO  RECEIVERS
      SKIP 1 OUTPUT LINE
      PRINT 1 LINE WITH A GROUP OF IJ FIELDS THUS
                    ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
      SKIP 1 OUTPUT LINE
      END '' HEADING
      FOR JI = 1 TO NO.OF.PTS, PRINT 1 LINE WITH JI, NO.PER.ROW(JI),
           AND A GROUP OF MATRIX.ORDER(JI,IJ) FIELDS THUS
            ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
      END '' REPORT
      START NEW PAGE
      RETURN
      END




      ROUTINE LPI

      DEFINE I, SYMBOL AS INTEGER VARIABLES
      DEFINE X, Y, NODE, MOBILITY.LPI, DISTANCE,SNR.L, SNR.H AS REAL VARIABLES
      LET LINES.V = 80
      START NEW PAGE
      SKIP 4 OUTPUT LINES
      PRINT 1 LINE AS FOLLOWS
           LP  XMTR   SNR.L   SNR.H  DISTANCE  FOREST
      SKIP 1 OUTPUT LINE
'START'  READ X, Y, NODE, SYMBOL, MOBILITY.LPI
      IF X EQ 99999 RETURN ALWAYS
      FOR I = 1 TO NO.OF.PTS, DO
      LET TMICA.LS = 0.
      LET TMICB.LS = 0.
      LET DISTANCE = SQRT.F((X-AX(I))**2+(Y-AY(I))**2)
      CALL ELEV GIVEN X, Y YIELDING TMACA.LS
      CALL ELEV GIVEN AX(I), AY(I) YIELDING TMACB.LS
      CALL TREES GIVEN X, Y YIELDING TREE.A.HT
      CALL TREES GIVEN AX(I), AY(I) YIELDING TREE.B.HT
      IF MOBILITY.LPI EQ 1  LET TMICA.LS = TREE.A.HT  ALWAYS
      IF MOBILITY(I) EQ 1  LET TMICB.LS = TREE.B.HT  ALWAYS
      LET XA.LS = X  LET YA.LS = Y  LET XB.LS = AX(I)  LET YB.LS = AY(I)
      LET NCVELS = 0
```

```
      CALL LOS
      IF VISFRB.LS LE 0, CYCLE ALWAYS
      LET NCVELS = TEMP.NCVELS
      CALL LOS
      LET WOODS = 0.0
      IF VISFRB.LS LE 0.0, CALL FOREST YIELDING FOREST.PERCENT
      IF FOREST.PERCENT LE 0.0  LET FOREST.PERCENT = 0.01 ALWAYS
      LET WOODS = FOREST.PERCENT * DISTANCE
      ALWAYS
      LET SNR.L =LINK.LOSS+11-10*LOG.10.F(DISTANCE**4/(ANT.A.HT*ANT.B.HT)**2)-
      WOODS*0.25*FREQ.L**0.75
      LET SNR.H =LINK.LOSS+11-10*LOG.10.F(DISTANCE**4/(ANT.A.HT*ANT.B.HT)**2)-
      WOODS*0.25*FREQ.H**0.75
      PRINT 1 LINE WITH NODE,NODE.NO(I),SNR.L,SNR.H,DISTANCE, WOODS AS FOLLOWS
          **   **     ****.*  ****.*  *****.*  *****.*
      LOOP  ''I''
      GO TO START
      END
```

ROUTINE FOR ELEV GIVEN X,Y YIELDING Z

```
''ROUTINE TO COMPUTE ELEVATION Z FOR GIVEN X,Y COORDINATES
DEFINE I,IX,IY,KOUNT,L AS INTEGER VARIABLES
DEFINE X,Y,Z,XS,YS,QI,FI AS REAL VARIABLES
DEFINE DUM.I AS A 1-DIMENSIONAL INTEGER ARRAY
LET IX=1+TRUNC.F((X-X.LO.BDRY)/GSIZE)
LET IY=1+TRUNC.F((Y-Y.LO.BDRY)/GSIZE)
IF IX LT 1 LET IX=1 ALWAYS
IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
IF IY LT 1 LET IY=1 ALWAYS
IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
LET DUM.I(*) = LIST.H(IX,IY,*)  ''DUMMY ARRAY TO SIMPLIFY INDEXING
LET KOUNT = DIM.F(DUM.I(*))
LET Z = DUM.I(1)
FOR L = 2 TO KOUNT DO
    LET I = DUM.I(L)
    LET XS=X-XC.H(I)        LET YS=Y-YC.H(I)
    LET QI=PXX.H(I)*XS*XS + PYY.H(I)*YS*YS + PXY.H(I)*XS*YS
    IF QI LT CRIT.H(I) CYCLE
    ELSE LET FI=PEAK.H(I)+HT.H(I)*(EXP.F(QI)-1.)
    IF FI GT Z LET Z=FI ALWAYS
LOOP  RETURN  END
```

```
ROUTINE KOVER GIVEN ZO,TMACT,SIZET,ZT,S,HTS,ZS,VISFIN YIELDING VISFOUT

DEFINE ZO,TMACT,SIZET,ZT,S,HTS,ZS,VISFIN,VISFOUT,EVIST   AS REAL VARIABLES
LET VISFOUT = VISFIN
IF S NE O.
    IF HTS GE ZS GO TO BLOCKED ELSE
    LET EVIST = MAX.F(TMACT,ZO+(HTS-ZO)/S)
    IF EVIST GE ZT GO TO BLOCKED ELSE
    IF EVIST LE ZT-SIZET RETURN ELSE
    LET VISFOUT = MIN.F(VISFOUT,(ZT-EVIST)/SIZET) RETURN
ELSE IF HTS LT ZO RETURN ELSE
'BLOCKED' LET VISFOUT = 0.      RETURN     END




ROUTINE TREES GIVEN X AND Y YIELDING T

''  ROUTINE TO COMPUTE TREE HEIGHT GIVEN A POINT ON THE BATTLEFIELD
DEFINE X,Y,T,XS,YS,QI,HT AS REAL VARIABLES
DEFINE IC,IX,IY,N,L AS INTEGER VARIABLES
DEFINE DUM.I AS A 1-DIMENSIONAL INTEGER ARRAY
LET T = O.
IF NCVELS EQ O RETURN ELSE
LET IX = 1 + TRUNC.F((X-X.LO.BDRY)/GSIZE)
LET IY = 1 + TRUNC.F((Y - Y.LO.BDRY)/GSIZE)
IF IX LT 1 LET IX = 1 ALWAYS
IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
IF IY LT 1 LET IY = 1 ALWAYS
IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
IF (IX LT 1) OR (IX GT NGRIDX) OR (IY LT 1) OR (IY GT NGRIDY) RETURN
ELSE LET DUM.I(*)= LIST.C(IX,IY,*)
```

```
LET N = DUM.I(1) + 1
IF N EQ 1 RETURN ELSE
FOR L = 2 TO N DO
    LET IC = DUM.I(L) LET HT=HT.E(IC)
    IF HT LE T CYCLE
    ELSE
    LET XS = X-XC.E(IC) LET YS = Y-YC.E(IC)
    LET QI = PXX.E(IC)*XS**2 + PYY.E(IC)*YS**2 + PXY.E(IC)*XS*YS
    IF QI GE 1. CYCLE
    ELSE LET T = HT
LOOP
RETURN
END




ROUTINE LOS

DEFINE I,K,N,L,IC,M       AS INTEGER VARIABLES
'' ALL VARIABLES EXCEPT THOSE DECLARED ABOVE ARE GLOBAL FOR USE IN LOS AND
''      ITS ASSOCIATED ROUTINES
LET VISFRA.LS = 1.0     LET VISFRB.LS = 1.0
LET XBA.LS = XB.LS - XA.LS      LET YBA.LS = YB.LS - YA.LS
IF XBA.LS EQ 0 AND YBA.LS EQ 0 RETURN ELSE
IF (SIZEA.LS + TMICA.LS LE 0.) OR (SIZEB.LS+TMICB.LS LE 0.) GO TO NO.LOS ELSE
IF TMICA.LS LT 0. LET VISFRA.LS = 1. + TMICA.LS / SIZEA.LS  ALWAYS
IF TMICB.LS LT 0. LET VISFRB.LS = 1. + TMICB.LS / SIZEB.LS   ALWAYS
LET ZA.LS = TMACA.LS + TMICA.LS + SIZEA.LS
LET ZB.LS = TMACB.LS + TMICB.LS + SIZEB.LS
LET ZBA.LS = ZB.LS - ZA.LS        ADD 1 TO <TREP
LET XBASQ.LS = XBA.LS **2     LET YBASQ.LS = YBA.LS **2
LET XYBA.LS = XBA.LS * YBA.LS
LET TWOXBA.LS = 2. * XBA.LS      LET TWOYBA.LS = 2. * YBA.LS
LET LAG.LS = LAGA.LS + LAGB.LS      LET CHTMAX.LS = 0.
''COMPUTE LIST OF GRIDSQUARES CROSSED BY A TO B LINE
LET NGRSQ.LS = 0
IF XBA.LS EQ 0. LET XBA.LS = 0.1 ALWAYS
IF XBA.LS GT 0.
    LET ISGX.LS = -1  LET XINC.LS = GSIZE/XBA.LS      JUMP AHEAD
ELSE LET ISGX.LS = 1    LET XINC.LS =-GSIZE/ XBA.LS
HERE     IF YBA.LS EQ 0. LET YBA.LS = 0.1 ALWAYS
```

```
IF YBA.LS GT 0.
    LET ISGY.LS = -1        LET YINC.LS = GSIZE/YBA.LS       JUMP AHEAD
ELSE LET ISGY.LS = 1    LET YINC.LS = -GSIZE/YBA.LS
HERE
LET IX.LS = 1 + TRUNC.F((XB.LS-X.LO.BDRY)/GSIZE)
LET IY.LS = 1 + TRUNC.F((YB.LS - Y.LO.BDRY) /GSIZE)
LET XSTEP.LS = (XB.LS-X.LO.BDRY-GSIZE*(IX.LS+0.5*(ISGX.LS-1.)))/XBA.LS
LET YSTEP.LS = (YB.LS-Y.LO.BDRY-GSIZE*(IY.LS+0.5*(ISGY.LS-1.)))/YBA.LS
'GRID.LOOP'
IF (IX.LS LT 1) OR (IX.LS GT NGRIDX) OR (IY.LS LT 1) OR (IY.LS GT NGRIDY)
     JUMP AHEAD
ELSE ADD 1 TO NGRSQ.LS
     LET IGX.LS(NGRSQ.LS) = IX.LS  LET IGY.LS(NGRSQ.LS) = IY.LS
HERE
IF XSTEP.LS LE 1. OR YSTEP.LS LE 1.
    IF XSTEP.LS LT YSTEP.LS
        ADD ISGX.LS TO IX.LS      ADD XINC.LS TO XSTEP.LS
        GO TO GRID.LOOP
    ELSE
    IF XSTEP.LS GT YSTEP.LS JUMP AHEAD
    ELSE ADD ISGX.LS TO IX.LS      ADD XINC.LS TO XSTEP.LS
    HERE ADD ISGY.LS TO IY.LS      ADD YINC.LS TO YSTEP.LS
    GO TO GRID.LOOP
ALWAYS  ''GRID LIST NOW COMPLETE IN IGX.LS, IGY.LS WITH NGRSQ.LS ENTRIES
IF NGRSQ.LS EQ 0 GO TO NO.LOS ELSE
'' NOW FIND WHICH COVER ELLIPSES INTERSECT THE A TO B LINE
'' AND CHECK LOS AT S1 AND S2 FOR EACH SUCH ELLIPSE
LET NELS.LS = 0
IF NCVELS    EQ 0 GO TO HILL.PROCESSING ELSE
FOR K = 1 TO NGRSQ.LS DO
    LET IX.LS = IGX.LS(K)      LET IY.LS = IGY.LS(K)
    LET DUM.I(*) = LIST.C(IX.LS,IY.LS,*)      LET N = DUM.I(1) + 1
    IF N EQ 1 CYCLE ELSE
    FOR L = 2 TO N DO
        LET IC = DUM.I(L)      LET CPK.LS = HT.E(IC)
        IF KCREP(IC) EQ KTREP CYCLE ELSE
        LET KCREP(IC) = KTREP
        LET RX.LS = XA.LS - XC.E(IC)     LET RY.LS = YA.LS - YC.E(IC)
        LET PXX.LS = PXX.E(IC)   LET PYY.LS = PYY.E(IC)   LET PXY.LS = PXY.E(IC)
        LET AA.LS = PXX.LS*XBASQ.LS + PYY.LS*YBASQ.LS  + PXY.LS*XYBA.LS
        LET BB.LS = PXX.LS*TWOXBA.LS*RX.LS + PYY.LS*TWOYBA.LS*RY.LS
            +PXY.LS*(RX.LS*YBA.LS + RY.LS*XBA.LS)
        LET CC.LS = PXX.LS*RX.LS**2 + PYY.LS*RY.LS**2 + PXY.LS*RX.LS*RY.LS -1.0
        LET ARG.LS = BB.LS**2 - 4.0*AA.LS*CC.LS
        IF ARG.LS LE 0. CYCLE ELSE
        LET SQ.LS = SQRT.F(ARG.LS)
        LET S1.LS = -(BB.LS+SQ.LS)/(2.0*AA.LS)
        LET S2.LS = (SQ.LS-BB.LS)/(2.0*AA.LS)
```

```
          IF S1.LS GE 1.0 CYCLE ELSE
          IF S2.LS LE 0.0 CYCLE ELSE
          IF LAG.LS NE 0 GO TO AIR ELSE
     ''BOTH A AND B ARE GROUND PLATFORMS
          IF S1.LS LT 0. GO TO NO.LOS ELSE
          IF S2.LS GT 1. GO TO NO.LOS ELSE
     ''FOREST IS BETWEEN A AND B
'GROUND' LET SS.LS = S2.LS      CALL TREE.CHECK
          LET SS.LS = S1.LS      CALL TREE.CHECK
          GO TO SAVE.ELL
'AIR'     IF S1.LS GE 0. AND S2.LS LE 1. GO TO GROUND ELSE
          IF S1.LS LT 0. AND S2.LS LE 1. GO TO A.IS.IN ELSE
          IF S1.LS GE 0. AND S2.LS GT 1. GO TO B.IS.IN ELSE
''BOTH A AND B ARE IN OR OVER TREES
          IF LAG.LS LE 1 OR TMICA.LS LT CPK.LS OR TMICB.LS LT CPK.LS GO TO NO.LOS
          ELSE  GO TO SAVE.ELL
'A.IS.IN'  ''A IS IN OR OVER TREES, B IS NOT
          IF LAGA.LS EQ 0 OR TMICA.LS LT CPK.LS GO TO NO.LOS ELSE
          LET SS.LS = S2.LS      CALL TREE.CHECK
          GO TO SAVE.ELL
'B.IS.IN'  ''  B IS IN OR OVER TREES, A IS NOT
          IF LAGB.LS EQ 0 OR TMICB.LS LT CPK.LS GO TO NO.LOS ELSE
          LET SS.LS = S1.LS      CALL TREE.CHECK
'SAVE.ELL' IF LATOB.LS EQ 1 AND VISFRB.LS LE 0. GO TO NO.LOS ELSE
          IF LBTOA.LS EQ 1 AND VISFRA.LS LE 0. GO TO NO.LOS ELSE
          ADD 1 TO NELS.LS       LET IEL.LS(NELS.LS) = IC
          LET CS1.LS(NELS.LS) = S1.LS     LET CS2.LS(NELS.LS) = S2.LS
          IF CPK.LS GT CHTMAX.LS LET CHTMAX.LS = CPK.LS     ALWAYS
     LOOP  ''BACK FOR NEXT ELLIPSE IN THIS GRID SQUARE
LOOP   ''BACK FOR NEXT GRID SQUARE
''   ALL ELLIPSES CHECKED AND SAVED
''   NOW START ON THE HILLS
'HILL.PROCESSING'
FOR K = 1 TO NGRSQ.LS DO
     LET IX.LS = IGX.LS(K)     LET IY.LS = IGY.LS(K)
     LET DUM.I(*) = LIST.H(IX.LS,IY.LS,*)
     LET N = DIM.F(DUM.I(*))
     LET BASE.LS = DUM.I(1)
     FOR L = 2 TO N DO
          LET I = DUM.I(L)   '' GIVING THE HILL NUMBER
          IF KHREP(I) EQ KTREP CYCLE ELSE
          LET KHREP(I) = KTREP
'' COMPUTE W = TOP OF HILL I ALONG A TO B LINE
          LET PXX.LS = PXX.H(I)  LET PYY.LS = PYY.H(I)  LET PXY.LS = PXY.H(I)
          LET RX.LS = XA.LS - XC.H(I)     LET RY.LS = YA.LS - YC.H(I)
          LET GQ.LS = PXX.LS*XBASQ.LS + PYY.LS*YBASQ.LS + PXY.LS*XYBA.LS
          LET FQ.LS = 2.0*(PXX.LS*RX.LS*XBA.LS + PYY.LS*RY.LS*YBA.LS) +
               PXY.LS*(RX.LS*YBA.LS + RY.LS*XBA.LS)
```

```
            IF GQ.LS EQ 0.0 CYCLE ELSE
            LET W.LS = -FQ.LS / (2.0*GQ.LS)
            IF ABS.F(W.LS) GT 5. CYCLE ELSE
            LET FSQ.LS = FQ.LS**2
            LET EQ.LS = PXX.LS*RX.LS**2 + PYY.LS*RY.LS**2 + PXY.LS*RX.LS*RY.LS
            LET POW.LS = EQ.LS - FSQ.LS / (4.0*GQ.LS)
            IF POW.LS LT -4.0 CYCLE ELSE
            LET PK.LS = PEAK.H(I)      LET HT.LS = HT.H(I)
            LET HHW.LS = PK.LS + HT.LS*(EXP.F(POW.LS)-1.)
            IF  HHW.LS LE BASE.LS CYCLE ELSE
            LET ZW.LS = ZA.LS + W.LS*ZBA.LS
            IF W.LS LT 0. OR W.LS GT 1. JUMP AHEAD ELSE
            IF HHW.LS GE ZW.LS GO TO NO.LOS ELSE
            IF NELS.LS EQ 0 JUMP AHEAD ELSE
            LET CVHTW.LS = 0.
            FOR M = 1 TO NELS.LS DO
                IF CS1.LS(M) GE W.LS OR CS2.LS(M) LE W.LS CYCLE ELSE
                LET IC = IEL.LS(M)
                IF CVHTW.LS LT HT.E(IC) LET CVHTW.LS = HT.E(IC) ALWAYS
            LOOP
            IF HHW.LS + CVHTW.LS GE ZW.LS GO TO NO.LOS ELSE
HERE        IF HHW.LS + CHTMAX.LS LT MIN.F(ZA.LS-SIZEA.LS,ZB.LS-SIZEB.LS) CYCLE ELSE
'' IF WE GET TO HERE, THEN NEED TO FIND LOWEST SIGHT LINE OVER HILL
'' NEWTON ITERATION FROM A TO B GIVING VISFRB.LS
            IF LATOB.LS EQ 1
                LET ZZ.LS = ZA.LS + HT.LS - PK.LS       LET VSUB.LS = 0.
                CALL NEWTON
                IF VISFRB.LS LE 0. GO TO NO.LOS ELSE
            ALWAYS
'' NEWTON ITERATION FROM B TO A GIVING VISFRA.LS
            IF LBTOA.LS EQ 1
                LET ZZ.LS = ZB.LS + HT.LS - PK.LS        LET VSUB.LS =  1.
                CALL NEWTON
                IF VISFRA.LS LE 0. GO TO NO.LOS ELSE
            ALWAYS
        LOOP   ''BACK FOR NEXT HILL
LOOP   ''BACK FOR NEXT GRID SQUARE
RETURN
'NO.LOS' LET VISFRA.LS = 0.     LET VISFRB.LS = 0.
RETURN END
ROUTINE NEWTON
DEFINE M, IC AS INTEGER VARIABLES
'' ALL VARIABLES ARE REAL AND GLOBAL EXCEPT M,IC AS ABOVE AND
''NCT.LS, NELS.LS, IEL.LS  WHICH ARE INTEGER GLOBAL
LET NCT.LS = 0
LET V.LS = W.LS      LET VM.LS = V.LS - VSUB.LS
LET HHV.LS = HHW.LS + HT.LS - PK.LS
LET TWOGV.LS = 2.*GQ.LS * V.LS
```

```
'TOP'  LET FCNV.LS = ZZ.LS + HHV.LS*((FQ.LS+TWOGV.LS)*VM.LS-1.)
LET DFCNV.LS = HHV.LS*VM.LS*(TWOGV.LS**2 + 2.*(GQ.LS + TWOGV.LS*FQ.LS)+FSQ.LS)
IF ABS.F(DFCNV.LS) LT 0.0000000001  RETURN ELSE
LET V.LS = V.LS - FCNV.LS/DFCNV.LS
IF ABS.F(V.LS) GT 5. RETURN ELSE
LET VM.LS = V.LS - VSUB.LS
LET TWOGV.LS = 2.*GQ.LS*V.LS
LET POW.LS = EQ.LS + FQ.LS*V.LS + GQ.LS*V.LS**2
IF POW.LS LT -4. RETURN ELSE
LET HHV.LS = HT.LS*EXP.F(POW.LS)
LET ELV.LS = ZZ.LS + VM.LS*(HHV.LS*(FQ.LS+TWOGV.LS))
IF ABS.F(ELV.LS - HHV.LS) GT 1.
    LET NCT.LS = NCT.LS + 1
    IF NCT.LS LT 10 GO TO TOP ELSE
ALWAYS
IF V.LS LT 0. OR V.LS GT 1. RETURN ELSE
'' WE HAVE A GOOD VALUE OF V  --  CHECK IT FOR FOREST COVERAGE
LET CVHTV.LS = 0.
FOR M = 1 TO NELS.LS DO
    IF CS1.LS(M) GE V.LS OR CS2.LS(M) LE V.LS CYCLE ELSE
    LET IC = IEL.LS(M)
    IF CVHTV.LS LT HT.E(IC) LET CVHTV.LS = HT.E(IC) ALWAYS
LOOP
LET HTV.LS = HHV.LS + PK.LS + CVHTV.LS - HT.LS
LET ZV.LS = ZA.LS + V.LS*ZBA.LS
IF VSUB.LS EQ 0.
CALL KOVER(ZA.LS,TMACB.LS,SIZEB.LS,ZB.LS,V.LS,HTV.LS,ZV.LS,VISFRB.LS) YIELDING
    VISFRB.LS
ELSE
CALL KOVER(ZB.LS,TMACA.LS,SIZEA.LS,ZA.LS,-VM.LS,HTV.LS,ZV.LS,VISFRA.LS) YIELDING
    VISFRA.LS
ALWAYS RETURN END
```

```
ROUTINE RES.TERR

''ROUTINE TO RESERVE AND READ IN DATA ARRAYS FOR TERRAIN HILLS, COVER
''     ELLIPSES, AND BATTLEFIELD COORDINATES
NORMALLY MODE IS REAL
DEFINE I,IX,IY,KOUNT,J,JX,JY                                  AS INTEGER VARIABLES
USE UNIT 14 FOR INPUT
READ NGRIDX,NGRIDY,GSIZE,X.LO.BDRY,Y.LO.BDRY,NHILLS   ''ALL GLOBAL
RESERVE IGX.LS(*), IGY.LS(*) AS NGRIDX + NGRIDY
RESERVE IEL.LS(*), CS1.LS(*),CS2.LS(*) AS 100
RESERVE LIST.H(*,*,*) AS NGRIDX BY NGRIDY BY *
RESERVE XC.H(*),YC.H(*),PEAK.H(*),HT.H(*),PXX.H(*),PYY.H(*),PXY.H(*),CRIT.H(*)
     AS NHILLS
RESERVE KHREP(*) AS NHILLS
LET KTREP=-INF.C
FOR I=1 TO NHILLS DO
     READ J
     IF I NE J PRINT 1 LINE WITH I AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN HILL DATA FOR HILL ***** XXXXX
     ALWAYS
     READ XC,YC,PEAK.H(I),ANG,ECC,SPRD,HT.H(I),CUTOFF
     LET A=LOG.E.F(HT.H(I)/(HT.H(I)-50.))               LET B=A*ECC**2
     LET ANG=ANG/RADIAN.C      LET SANG=SIN.F(ANG)      LET CANG=COS.F(ANG)
     LET PXX.H(I)=-(A*CANG**2 + B*SANG**2)/(SPRD**2)
     LET PYY.H(I)=-(A*SANG**2 + B*CANG**2)/(SPRD**2)
     LET PXY.H(I)=(2.*CANG*SANG*(B-A))/(SPRD**2)
     LET XC.H(I)=XC*100.
     LET YC.H(I)=YC*100.
     LET KHREP(I)=-INF.C
     IF CUTOFF GE HT.H(I) LET CRIT.H(I)=-5.
     ELSE LET CRIT.H(I)=LOG.E.F((HT.H(I)-CUTOFF)/HT.H(I))
     ALWAYS
LOOP
FOR IX = 1 TO NGRIDX DO
FOR IY = 1 TO NGRIDY DO
     READ JX,JY,KOUNT
     IF IX NE JX OR IY NE JY PRINT 1 LINE WITH IX,IY AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN LIST.H DATA FOR GRID **** **** XXXXX
     ALWAYS RESERVE LIST.H(IX,IY,*) AS KOUNT+1
     FOR I = 1 TO KOUNT+1 READ LIST.H(IX,IY,I)
LOOP     LOOP
READ NCVELS
IF NCVELS EQ 0 USE UNIT 5 FOR INPUT  RETURN
ELSE RESERVE LIST.C(*,*,*) AS NGRIDX BY NGRIDY BY *
RESERVE XC.E(*),YC.E(*),HT.E(*),PXX.E(*),PYY.E(*),PXY.E(*),KCREP(*) AS NCVELS
FOR I = 1 TO NCVELS DO
     READ J
     IF I NE J PRINT 1 LINE WITH I AS FOLLOWS
```

```
XXXXX INPUT DATA SEQUENCE ERROR IN COVER ELLIPSE NUMBER ***** XXXXX
      ALWAYS
      READ XC,YC,HT.E(I),ANG,AMAJ,AMIN
      LET ANG = ANG/RADIAN.C    LET SANG = SIN.F(ANG)    LET CANG = COS.F(ANG)
      LET PXX.E(I) = (CANG/AMAJ)**2 + (SANG/AMIN)**2
      LET PYY.E(I) = (SANG/AMAJ)**2 + (CANG/AMIN)**2
      LET PXY.E(I) = 2.*SANG*CANG*(1./AMAJ**2 - 1./AMIN**2)
      LET XC.E(I) = XC * 100.    LET YC.E(I) = YC * 100.
      LET KCREP(I)= -INF.C
LOOP
FOR IX = 1 TO NGRIDX DO
FOR IY = 1 TO NGRIDY DO
      READ JX,JY,KOUNT
      IF IX NE JX OR IY NE JY PRINT 1 LINE WITH IX,IY AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN LIST.C DATA FOR GRID **** **** XXXXX
      ALWAYS RESERVE LIST.C(IX,IY,*) AS KOUNT+1
      LET LIST.C(IX,IY,1 ) = KOUNT
      FOR I = 2 TO KOUNT + 1  READ LIST.C(IX,IY,I)
LOOP    LOOP
USE UNIT 5 FOR INPUT
RETURN END



ROUTINE TREE.CHECK

LET XS.LS = XA.LS + SS.LS*XBA.LS    LET YS.LS = YA.LS + SS.LS*YBA.LS
CALL ELEV GIVEN XS.LS, YS.LS YIELDING HTS.LS
ADD CPK.LS TO HTS.LS
LET ZS.LS = ZA.LS + SS.LS * ZBA.LS
IF LATOB.LS EQ 1
      CALL KOVER(ZA.LS,TMACB.LS,SIZEB.LS,ZB.LS,SS.LS,HTS.LS,ZS.LS,VISFRB.LS)
      YIELDING VISFRB.LS
ALWAYS
IF LBTOA.LS EQ 1
      CALL KOVER(ZB.LS,TMACA.LS,SIZEA.LS,ZA.LS,1.0-SS.LS,HTS.LS,ZS.LS,VISFRA.LS)
      YIELDING VISFRA.LS
ALWAYS    RETURN   END
```

```
ROUTINE FOREST YIELDING FOREST.ATOB

DEFINE I AS INTEGER VARIABLE
DEFINE FOREST.ATOB,X,Y,ELEV.XY,TREE.XY,Z,Z.OT.LINE,DIF AS REAL VARIABLES
LET FOREST.ATOB = 0.0
FOR I = 1 TO 100, DO
     LET X = XA.LS + I/100*(XB.LS - XA.LS)
     LET Y = YA.LS + I/100*(YB.LS - YA.LS)
     CALL ELEV GIVEN X,Y YIELDING ELEV.XY
     CALL TREES GIVEN X,Y YIELDING TREE.XY
     LET Z = ELEV.XY + TREE.XY
     LET Z.OT.LINE = ZA.LS + I/100*(ZB.LS - ZA.LS)
     LET DIF = Z.OT.LINE - Z
     IF DIF LE 0.0, LET FOREST.ATOB = FOREST.ATOB + 0.01  CYCLE
     ALWAYS
LOOP ''I
RETURN
END


//GO.SIMU14 DD UNIT=2314,VOL=SER=PAT001,
//   DSN=HUNTERR,DISP=SHR
  3   3
5000        74




99999    99999    99     99       9
```

```
//TGK1015 JOB (1420,0238,DC91,,15),'TRY ONE',TIME=10
// EXEC FORTCLGW
//FORT.SYSIN DD *
C PLOT FOR 10 BY 30 KM HUNFELD TERRAIN BOX
      DIMENSION IOPT(10),BX(7),BY(7),EX(7),EY(7),X(3600),Y(3600),      PL000020
     1  ITR(100),ITITLE(20)                                            PL000030
      DATA BX/-500.,30500.,30500.,-500.,-500.,     0.,1./,
     1     BY/-500.,-500.,10500.,10500.,-500.,     0.,1./,
     2     EX/0.,30000.,30000.,0.,0.,0.,1./,
     3     EY/0.,0.,10000.,10000.,0.,0.,1./
      DATA LMASK1/Z0F0F/                                               PL000080
C                                                                      PL000090
C INPUT OPTIONS AS  1 = DESIRED,  0 = NOT DESIRED                      PL000100
C     IOPT(1) -- COORDINATE GRID                                       PL000110
C         (2) -- LABEL COORDINATES                                     PL000120
C         (3) -- TERRAIN CONTOUR MAP                                   PL000130
C         (4) -- ACCENT CONTOURS DIVISIBLE BY 100.                     PL000140
C         (5) -- FORESTS SHADED                                        PL000150
C         (6) -- DRAW LINES (EG. ROUTES)                               PL000160
C         (7) -- DRAW SYMBOLS (EG. POSITIONS)                          PL000170
C         (8) -- TITLE                                                 PL000180
C                                                                      PL000190
      READ(5,7) IOPT                                                   PL000200
7     FORMAT(10I1)                                                     PL000360
C BATTLEFIELD LOWER LEFT CORNER COORDS IN METERS                       PL000220
      XLOBY=40000.
      YLOBY=10000.
C                                                                      PL000250
C PLOT FRAME                                                           PL000260
C                                                                      PL000270
      CALL PLOTS(0,0,0)                                                PL000280
      CALL NEWPEN(5)                                                   PL000290
      CALL LINE(BX,BY,5,1,0,0)                                         PL000300
      CALL LINE(EX,EY,5,1,0,0)                                         PL000310
      CALL NEWPEN(1)                                                   PL000320
C                                                                      PL000330
C PLOT COORDINATE GRID                                                 PL000340
C                                                                      PL000350
      IF (IOPT(1).NE.1) GO TO 200                                      PL000360
      WRITE(6,107)
107   FORMAT(' OPTION 1 -- COORDINATE GRID')
      CALL GRID(0.,0.,30,1000.,10,1000.,LMASK1)
C                                                                      PL000380
C PLOT COORDINATE LABEL NUMBERS                                        PL000390
C                                                                      PL000400
200   IF(IOPT(2).NE.1) GO TO 300                                       PL000410
```

```
      WRITE(6,207)
207   FORMAT(' OPTION 2 -- COORDINATE LABELS')
      CX=-100.                                                          PL000420
      CY=-315.
      CYT=10185.
      DX=-445.
      DXT=30055.
      DY=-65.
      XB=XLOBY/1000.                                                    PL000480
      YB=YLOBY/1000.                                                    PL000490
      HT=130.
      DO 230 I=1,31
      CALL NUMBER(CX,CY,HT,XB,0.0,-1)                                   PL000510
      CALL NUMBER(CX,CYT,HT,XB,0.0,-1)                                  PL000520
      CX=CX+1000.                                                       PL000530
230   XB=XB+1                                                           PL000540
      DO 250 I=1,11                                                     PL000500
      CALL NUMBER(DX,DY,HT,YB,0.0,-1)                                   PL000550
      CALL NJMBER(DXT,DY,HT,YB,0.0,-1)                                  PL000560
      DY=DY+1000.                                                       PL000570
250   YB=YB+1                                                           PL000580
C                                                                       PL000590
C PLOT TERRAIN CONTJJR MAP                                              PL000600
C                                                                       PL000610
300   IF(IOPT(3).NE.1) GO TO 500                                        PL000620
      WRITE(6,307)
307   FORMAT(' OPTION 3 -- TERRAIN CONTOUR LINES')
      IF (IOPT(4).EQ.1) WRITE(6,407)
407   FORMAT(' OPTION 4 -- ACCENT 100 M. CONTOURS')
310   READ(3,317,END=390) NP,CV                                         PL000630
317   FORMAT(I5,F10.0)                                                  PL000640
      READ(3,327) (X(I),Y(I),I=1,NP)                                    PL000650
327   FORMAT(8F10.2)
      X(NP+1)=0.                                                        PL000670
      X(NP+2)=1.                                                        PL000680
      Y(NP+1)=0.                                                        PL000690
      Y(NP+2)=1.                                                        PL000700
      CALL NEWPEN(1)                                                    PL000710
      IF(IOPT(4).NE.1) GO TO 350                                        PL000720
C
C     ACCENT CONTOURS DIVISIBLE BY 100.                                 PL000740
C
      ICV=CV/100.                                                       PL000760
      XXCV=CV-ICV*100.                                                  PL000770
      IF(ABS(XXCV).LT.0.1)  CALL NEWPEN(4)                              PL000780
350   CALL LINE(Y,X,NP,1,0,0)
      GO TO 310                                                         PL000800
C OUT OF DATA                                                           PL000810
```

```
390    CALL NEWPEN(1)                                                   PL000820
C                                                                       PL000830
C SHADE FORESTED AREAS                                                  PL000840
C                                                                       PL000850
500    IF(IOPT(5).NE.1) GO TO 600                                       PL000860
       WRITE(6,517)
517    FORMAT(' OPTION 5 -- SHADE FORESTS')
       HT=75.                                                           PL000870
       XC=50.                                                           PL000880
       DO 570 I=1,300
       READ(2,507) (ITR(J),J=1,100)                                     PL000900
507    FORMAT(50I1,30X)                                                 PL000910
       YC=50.                                                           PL000920
       DO 540 J=1,100                                                   PL000930
       IF(ITR(J).EQ.0) GO TO 520                                        PL000940
       CALL SYMBOL(XC,YC,HT, 9,0.,-1)
520    YC=YC+100.                                                       PL000960
540    CONTINUE                                                         PL000970
       XC=XC+100.                                                       PL000980
570    CONTINUE                                                         PL000990
C                                                                       PL001000
C PLOT LINES (EG. ROJTES)                                               PL001010
C
600    IF(IOPT(6).NE.1) GO TO 700                                       PL001030
       WRITE(6,627)
627    FORMAT(' OPTION 6 -- PLOT LINES')
       CALL NEWPEN(2)                                                   PL001040
610    READ(5,607) NP
607    FORMAT(I5)
       IF(NP.EQ.999) GO TO 690
       READ(5,617) (X(I),Y(I),I=1,NP)
617    FORMAT(8F10.0)
       X(NP+1)=0.
       X(NP+2)=1.
       Y(NP+1)=0.
       Y(NP+2)=1.
       CALL LINE(X,Y,NP,1,0,0)
       GO TO 610
690    CALL NEWPEN(1)
C
C PLOT SYMBOLS (EG. POSITIONS)
C
700    IF(IOPT(7).NE.1) GO TO 800
       WRITE(6,707)
707    FORMAT(' OPTION 7 -- PLOT POSITIONS')
       HT = 100.
       CALL NEWPEN(4)
710    READ(5,717) XC, YC, I, ISYM
```

```
717    FORMAT(F5.0,4X,F5.0,4X,I2,4X,I3)
       IF(ISY4.EQ.999) GO TO 800
       XC = XC - XLOBY
       YC = YC - YLOBY
       CALL SYMBOL(XC,YC,HT,ISYM,0.,-1)
       Z = I
       XC = XC + 50.
       YC = YC + 50.
       CALL NUMBER(XC,YC,HT,Z,0.0,-1)
       GO TO 710
C
C PLOT TITLE
C
800    IF(IOPT(8).NE.1) GO TO 900
       CALL NEWPEN(1)
       READ (5,807) ITITLE
807    FORMAT(20A4)
       WRITE(6,817) ITITLE
817    FORMAT(' OPTION 8 -- TITLE  ',20A4)
       XC=-700.
       YC=-400.
       HT=135.
       CALL SYMBOL(XC,YC,HT,ITITLE,90.0,80)
900    CONTINJE
       CALL PLOT(0.,0.,999)
       STOP
       END

//GO.PLOTPARM DD *
 &PLOT XMIN=-999.,XMAX=32000.,YMIN=-999.,YMAX=12000.,UNITS=.0254,
 SCALE=.00004,STRIP=14000.    &END
//GO.FT02F001 DD UNIT=2314,VOL=SER=PAT001,DSN=PLTHNTR,DISP=SHR
//GO.FT03F001 DD UNIT=2314,VOL=SER=PAT001,DSN=PLTHNCL,DISP=SHR
//GO.SYSIN DD *
1111101100




00000     00000     00     999
HUNFELD 10 X 30 TERRAIN CONTOURS WITH FORESTS -- MARCH 1980 -- JKH
```

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